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SOME SIMPLE METHODS FOR THE ASSESSMENT OF TROPICAL FISH STOCKS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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SOME SIMPLE METHODS FOR THE ASSESSMENT OF TROPICAL FISH STOCKS

by

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PREPARATION OF THIS PAPER

This document is a revised version of FAO Fisheries Circular No. 729, issued in English and French. The present version will be available also in Spanish.

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ABSTRACT

This selection of methods is based on lecture notes used at a FAO/DANIDA training course held in Mombasa, Kenya, in May-June 1980. The methods presented are: regression and correlation, estimation of growth parameters from length-frequency data, estimation of mortalities (total, natural, fishing mortality) and analysis of catch and effort data.

Only methods that are inherently simple and applicable in the tropics are discussed in detail while more advanced concepts such as the distinction between different forms of overfishing, stock-recruitment relationships, multispecies interactions are introduced in the form of an essay. A brief annotated bibliography of tropical fish stock assessment is included.

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FOREWORD

The present report provides an introduction to the methods of stock assessment particularly tailored to the needs of fisheries workers concerned with the complex resources of the tropical and subtropical areas of the world. In adapting existing methods (largely developed in the temperate and cold temperate regions of the world) for use in the tropics, the author has attempted to illustrate the main principles in as simple and direct way as possible, drawing upon concrete examples from actual published fishery data.

The text of this paper is taken, largely unchanged, from the notes of the lectures given by the author at the FAO/DANIDA Training Course on "The Methodology of Fisheries Science (Biology)", held from 19 May to 14 June 1980 in the Kenya Marine Fisheries Research Institute (KMFRI) in Mombasa, specifically aimed at an audience drawn from countries bordering on the Western Indian Ocean. This text is an improved version of FAO Fish. Circ. No. 729.

The course followed the usual FAO format: a brief, streamlined exposition of the main points of the subject-matter was followed by roundtable discussions and worked examples during which the pros and cons of the different methods and pitfalls in their application were explained fully. The worked examples used in the course are given in the text of the lecture, and it only remains to point out to the student reader that the application of any method (especially a 'short-cut' method) should not ignore the principles underlying the application of scientific methods in marine science.

These principles may be briefly summarized by four questions which the worker should ask himself or herself before and during the course of the analysis:

1. Were the basic data used in the analysis collected following statistically valid procedures?

2. Are the basic data in accordance or conflict with what else you know about the population or species in this or other areas?

3. In carrying out the anlysis, have you followed statistically valid procedures in either selecting the data to analyse, or in interpreting the data?

4. Once again, are the results in general accord with the known biology of the species?

If all these questions are asked before and during the analysis, then the results of a particular procedure may be viewed with the appropriate degree of confidence, particularly if the assumptions underlying each method are understood and borne in mind at all times.

J. F. Caddy
FAO, Rome
February 1983

1. DECK SAMPLING AND CATCH RECORDING PROCEDURES

The following steps pertain to methods for sorting the catch of a fishery research vessel such that the catch composition, both by weight and number of each species (group) can be established.

Step 1 Remove all sea snakes and other venomous or otherwise dangerous animals. Also remove turtles, and if alive, return these to the sea. Record number and kind of animals removed.

Step 2 Remove inorganic debris and plant material. Record type of material removed.

Step 3 Remove the larger fishes that are readily visible and place them in a box.

Step 4 Wash the remainder of the catch (of small fish) if necessary, and mix with shovels.

Step 5 Put the mixed catch in boxes, while continuing to remove larger fishes and putting them in the box mentioned in Step 3. The boxes should be filled simultaneously, not one after the other, and it should be made certain that all boxes contain the same weight of fish.

Step 6 Count the number of boxes with small fishes and record.

Step 7 A rule of thumb is to take one box out of every five at random for subsampling. Record number of boxes taken for subsampling as B_1, B_2, B_3, etc.

Step 8 The box(es) taken for subsampling is (are) then treated as follows:

- weigh the total catch in B_1 and record;
- place fish of B_1 on a sorting table and sort to species level as far as food fishes and valuable crustaceans (e.g., shrimp) are concerned, and to taxonomic groupings as well-defined as possible (e.g., genus, family, etc.), for the other groups (the non-edible fishes and miscellaneous crustaceans);
- repeat procedure, if appropriate for the other boxes (B_2, B_3, etc.).

Step 9 If more than one box were sorted, compute, for each species (or higher taxonomic group) the total weight and number in all sorted boxes.

Step 10 Multiply the numbers and weight of fishes and invertebrate by species (or higher taxonomic group) by the ratio of the number of unsorted to sorted boxes.

Step 11 Weigh and count the larger fishes mentioned in Steps 3 and 5, by species (very large fish should be weighed individually and measured).

Step 12 Add, when there is an overlap (when the fishes of a certain species occurred both in the sorted boxes of small fishes and in the large fish box) the weights and numbers obtained in Step 11 to the weights and numbers in Step 10.

Step 13 Step 12 (as well as Step 11, when there is no overlap) provide estimates of total catch, both in weight and number, by species or higher taxonomic groups. Record the totals, both in weight and numbers into an appropriate fishing log and convert to catch per hour if fishing time was less or more than one hour. During surveys, this step must be completed after each haul, or every evening at the latest, to preclude loss of information.

Step 14 In addition to catch sampling, identifying and recording, the work of the fishery biologist generally includes among other things:

- collecting length frequency data;
- collecting miscellaneous biological information on the fish caught, e.g., concerning their weight and maturity;

- collecting and preserving specimens for further studies onshore;
- collecting oceanographic data.

The methods generally used for the various activities in Step 14 are discussed in details in various manuals available from FAO, e.g., in Holden and Raitt (1974).

The procedure outlined here is adapted from Losse and Dwippongo (1977).

2. STATISTICS: REGRESSION AND CORRELATION

Introduction

The work conducted by fishery biologists generally requires a fair amount of statistical analysis and most courses in fishery biology therefore include elementary statistics, at least.

Most often, however, lack of practice causes one to forget what was learnt, which results in a very valuable tool remaining underutilized.

This note aims at briefly recalling two very powerful statistical techniques - regression and correlation analysis - and to indicate some of their most common fields of application by fishery biologists.

Linear Regression

Put simply, linear regression is a technique for quantifying the relationship that can be seen when a scatter diagram involving two variables is drawn (Figure 1a), which relationship being summarized by a "best fitting" equation of the form:

$$y = a + bx \qquad (1)$$

In this equation, y represents the coordinate values along the vertical axis of the graph (ordinate), while x represents the coordinate values along the horizontal axis (absissa). The value of "a" (which can be negative, positive or equal to zero) is called the intercept, while the value of b (which can be negative or positive) is called the slope or regression coefficient.

Table 1

Data set for calculating a regression (a and b) and correlation coefficient (r)

Number	x-values	y-values	Number	x-values	y-values
1	9.0	0.50	7	6.7	1.00
2	9.4	0.50	8	8.4	0.50
3	7.4	1.23	9	8.0	0.50
4	9.7	1.00	10	10.0	0.50
5	10.4	0.30	11	9.2	0.50
6	5.0	1.50	12	6.2	1.00
			13	7.7	0.50

The procedure to obtain values of a and b for a given set of y and x data pairs (such as in Figure 1 and/or Table 1) is as follows:

Step 1 Compute, for each pair of y, x values the quantities x^2, y^2 and $x \cdot y$.

Step 2 Compute the sums (Σ) of these quantities for all x, y data pairs, along with the sums of the x and y values. The results of Steps 1 and 2 should look similar to this:

Number of data pairs	x	x^2	y	y^2	$x \cdot y$
1	...	...	...	...	...
2	...	...	...	...	...
3	...	...	...	...	...
.					
.					
.					
n	...	...	...	...	...
Names of sums	Σx	Σx^2	Σy	Σy^2	$\Sigma x \cdot y$

Step 3 Estimate the slope (b) by means of the relationship

$$b = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}} \qquad (2)$$

Step 4 Estimate the intercept (a) by means of the relationship

$$a = \left[\frac{\Sigma y}{n} - \left(b \cdot \frac{\Sigma x}{n}\right)\right] \qquad (3)$$

Using values of "a" and "b" obtained by means of Equations 2 and 3, one then can draw through the points of a scatter diagram the best fitting straight line and visually assess if the points are well "explained" by the line (Figure 1b).

Correlation

Correlation analysis is closely related to regression analysis and both can be viewed, in fact as two aspects of the same thing.

The correlation between two variables, is, again put in the simplest terms, the degree of association between two variables. This degree of association is expressed by a single value called a correlation coefficient (r), which can take values ranging between -1 and +1. When r is negative, it means that one variable (either x or y) tends to decrease as the other increases - there is a "negative correlation" (corresponding to a negative value of b in regression analysis). When r is positive, on the other hand, it means that the one variable increases with the other (which corresponds to a positive value of b in regression analysis).

Values of r are easily computed for a set of x, y data pairs, using the same table and sums as shown in Step 2 of the "regression" section of this note. Thus r can then be obtained - indirectly - from the relationship

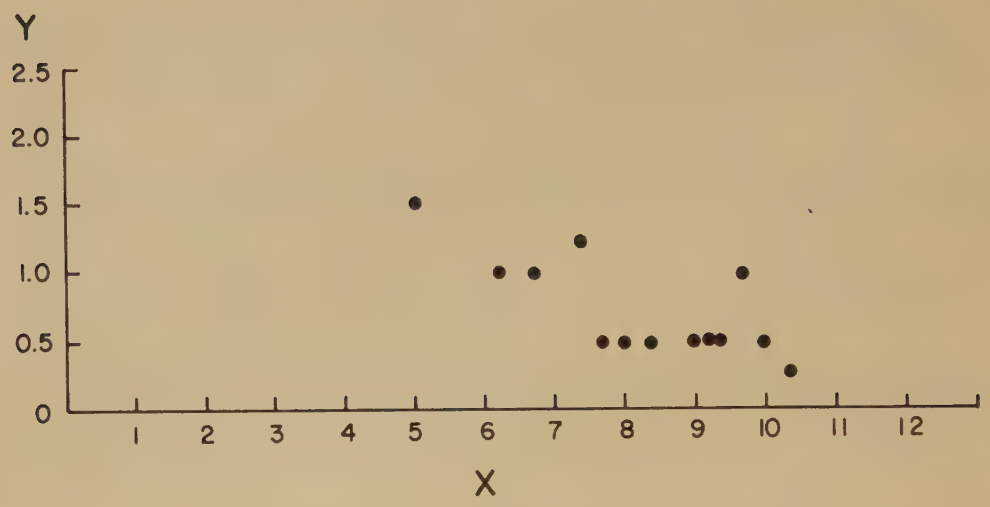

Figure 1a A scatter diagram (or scattergram) of x, y values. Note that y generally decreases as x increases, suggesting negative regression and correlation coefficients (based in Table 1).

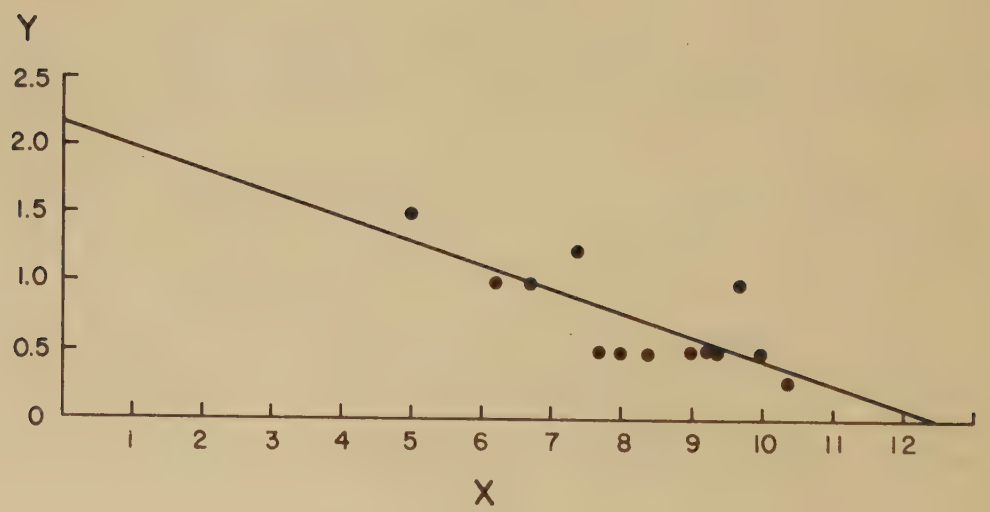

Figure 1b Same data as in 1a, but fitted with the regression $y = 2.16 - 0.173$, with $r = -0.756$

$$r^2 = \frac{\left[\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}\right]^2}{\left[\Sigma x^2 - \frac{(\Sigma x)^2}{n}\right] \cdot \left[\Sigma y^2 - \frac{(\Sigma y)^2}{n}\right]} \qquad (4)$$

which provides a value of the "coefficient of determination" (= r^2). All we need is then to compute

$$|r| = \sqrt{r^2} \qquad (5)$$

that is to take the square root of the coefficient of determination to obtain the (absolute) value of r, and then to add the sign (+ or -) depending on whether the correlation is positive or negative (which can be assessed by visual inspection of a scattergram or by computing the b value of the corresponding regression and using for r the sign of b).

When we compute values of r, we would also like to know, however, whether the correlation that was identified could have arisen by chance alone. This can be established by testing whether the computed value of r is "significant" that is whether the (absolute) value of r is higher than, or equal to a "critical" value of r as given in a statistical table (see table of critical values of r in Appendix 1).

Exercise: Compute a, b and r for the data given in Table 1 and test, by means of the table in Appendix 1 whether the computed value of r is significant at P = 0.01 and P = 0.05.

Linearizing Transformation in Regression Analysis

Both the regression and correlation analysis, as outlined above are based on the assumption of a "linear" relationship between the two variables involved (meaning that the best fitting line is straight). There are many cases in fishery biology, however, where the relationship between two variables is non-linear, and a well known example for this is the length-weight relationship, where

$$W = \alpha \cdot L^b \qquad (6)$$

where the weight (W) is proportional to a certain power (b) of the length (L) (see Figure 2a).

Length-weight data can, however, be fitted with a (linear) regression if logarithms are taken of both sides, resulting in

$$\log_{10} W = a + b \log_{10} L \qquad (7)$$

As may be seen from Figure 2b, the logarithm of the length and weight are fitted extremely well by a linear regression, where

$$y = \log_{10} W \qquad (8a)$$

and

$$x = \log_{10} L \qquad (8b)$$

Thus, fitting a length weight relationship of the form given in Expression 6 to a set of length/weight data (such as given in Table 2) consists of the following:

Table 2

Data for the estimation of a length-weight relationship in the threadfin bream *Nemipterus marginatus*[1/]

Number	TL (cm)	W (g)	Log_{10} L (=x)	Log_{10} W (=y)
1	8.1	6.3	0.908	0.799
2	9.1	9.6	0.959	0.982
3	10.2	11.6	1.009	1.064
4	11.9	18.5	1.076	1.267
5	12.2	26.2	1.086	1.425
6	13.8	36.1	1.140	1.558
7	14.8	40.1	1.170	1.603
8	15.7	47.3	1.196	1.675
9	16.6	65.6	1.220	1.817
10	17.7	69.4	1.248	1.841
11	18.7	76.4	1.272	1.883
12	19.0	82.5	1.279	1.916
13	20.6	106.6	1.314	2.028
14	21.9	119.8	1.340	2.078
15	22.9	169.2	1.360	2.228
16	23.5	173.3	1.371	2.239

1/ From the southern tip of the South China Sea. Original

Step 1 Take the logarithm of the length and weight values.

Step 2 Compute the sums given in the regression section, with x and y values as defined in 8a and 8b.

Step 3 Compute a and b using Equations 2 and 3.

Step 4 Take the antilogarithm of a to obtain α in Equation 6.

Step 5 Write your version of Equation 6.

Step 6 Using the sums computed in Step 2, compute the value of r^2 and r, and check significance.

Exercise: (a) Perform Steps 1 to 6 (with P = 0.01) for the length-weight data given in Table 2.

(b) List other linearizing transformations, and give examples of their use in fishery biology.

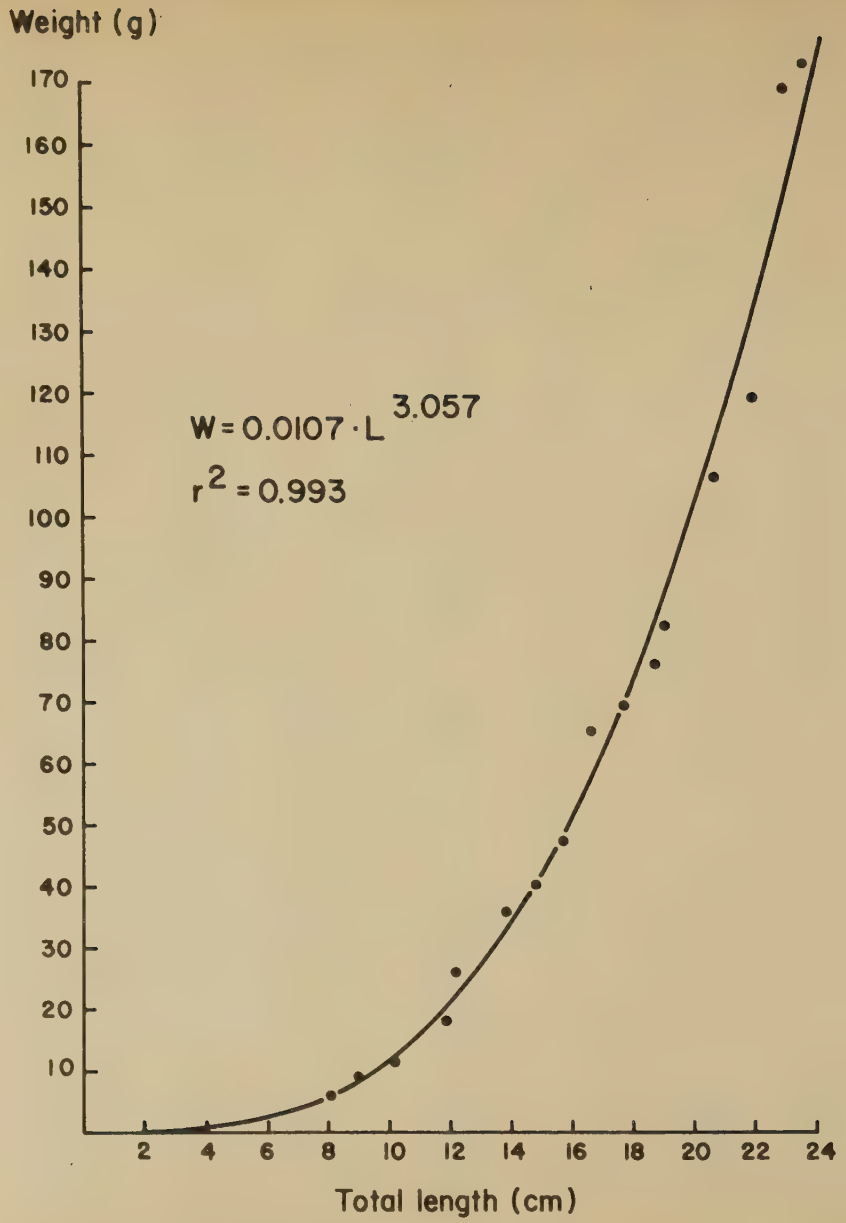

Figure 2a Length-weight relationship of *Nemipterus marginatus* in the South China Sea (based on data in Table 2)

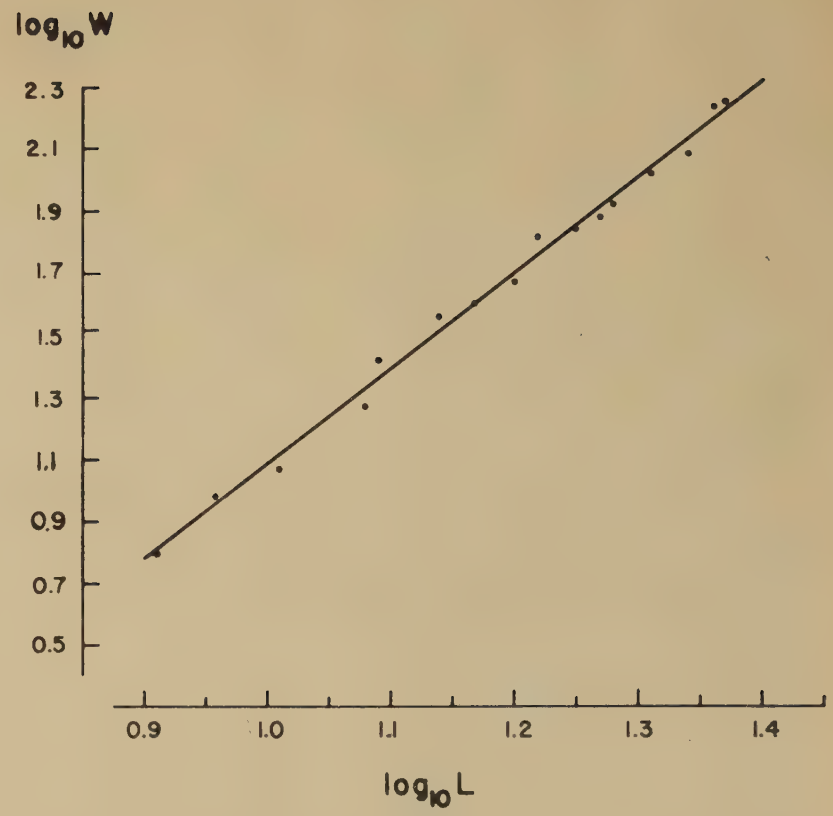

Figure 2b The same data converted to base 10 logarithms

3. METHODS FOR OBTAINING GROWTH PARAMETERS FROM LENGTH-FREQUENCY DATA OF TROPICAL FISH

The study of fish growth and of phenomena related to growth such as maturation, migration, food and feeding habits is central to fishery biology. Indeed, it is largely with growth studies that fishery biology established itself as a field of its own by the end of the last century.

Knowledge of how the fishes of a given stock grow is essential for most stock assessment purposes, both in the tropics and elsewhere, since it is the growth of individual fishes which provide from year to year the catch taken by a fishery.

For practical reasons, the available information on the growth of fishes of a given stock is generally reduced to and expressed by means of a single equation, such as the Von Bertalanffy Growth Formula (VBGF), the simplest version of which has the form

$$L_t = L_\infty(1-e^{-K(t-t_o)}) \qquad (9)$$

Where L_∞ is the mean length the fish would reach if they were to grow to a very old age (indefinitely, in fact)

K is a growth coefficient

t_o is the "age" the fish would have had at length zero if they had always grown according to the equation (t_o generally has a negative value)

and where

L_t is the length at age t.

The biological data which can be used to obtain information ("growth data") from which growth parameters can be estimated are of three basic types:

1. Tagging - recapture data on (or direct observation of the growth of) individual fishes.

2. Periodic markings (annual, or daily) on skeletal parts such as scales, otoliths, or other bones (or cartilage in elasmobranchs).

3. Size - frequency data; most commonly length-frequency data (such data, it must be emphasized, never provide absolute age estimate, and hence no value of t_o).

In spite of frequent criticism, the methods for the analysis of length frequency data have found, in the tropics, wider applications than the study of skeletal parts, while tagging studies have generally been underutilized. The reason for this is that it is generally easier to analyse length frequency data than to study skeletal parts and that much less equipment is needed; this also applies to the comparison with tagging studies.

Methods for the Analysis of Length-Frequency Data

The methods currently in use for the analysis of length-frequency data all find their origin in the work of Petersen (1892 and subsequent years). Traditionally, however, the name of Petersen has been associated with only one of the specific approaches commonly used, such that we may distinguish three methods for the analysis of length-frequency data.

1. The "Petersen method"
2. The "Modal class progression analysis"
3. A combination of methods 1 and 2 which may be called the "integrated method".

With the "Petersen method", assumptions are made as to the time interval separating the various peaks of one length-frequency sample, these peaks being assumed to represent distinct age groups (Figure 3).

With the second method, assumptions are made as to which of the peaks can be interconnected that belong to various samples arranged sequentially in time (Figure 4).

As Figures 3 and 4 show, the methods are quite subjective in the sense that several options are available for attributing ages to the various age groups (in Figure 3) or for interconnecting peaks (in Figure 4). Thus, both the "Petersen method" and the "modal class progression analysis" are often fraught with uncertainties. Some of these uncertainties can be overcome, however, by combining the two methods to an "integrated method" in which an attempt is made to draw a growth curve (e.g., with a curved ruler) directly upon the length-frequency samples sequentially arranged in time (as in Figure 5) or onto the same sample repeated over and over along the time axis (as in Figure 6).[1/] The method is based on the following tenets:

(1) Length growth in fishes is at first rapid, then decreases smoothly and is, for the population as a whole, best approximated by a long continuous curve, rather than by several, short straight segments.

(2) A single, smooth growth curve interconnecting the majority of the peaks of sequentially arranged length-frequency samples is likely to represent the average growth of the fishes of a given stock.

(3) The growth patterns repeat themselves from year to year (which is also assumed when the "annuli" of otoliths are counted).

Thus, the curve in Figure 5 which interconnects most of the peaks of the 1957 *Leiognathus bindus* samples of Balan (1967) can be used to estimate the growth parameters of that species of slipmouth. An additional example for the application of the integrated method to length-frequency data of tropical fishes may be given here (Figure 7), pertaining to length-frequency data on *Sardinella sirm* from the Java Sea. Note that the length-frequency data, as presented by their original authors do not suggest any growth process, while the same data redrawn in the appropriate manner suggest a clear growth pattern and a single major growth curve which, when drawn, can be used to estimate growth parameters in this fish.

This example illustrates once more the major features of the integrated method:

(1) The intervals on the time axis between the various samples must be proportional to the time elapsed between the sampling dates.

(2) The original data must be plotted at least twice, or more along the time axis, which allows for longer, stabilized growth curves to be drawn and for all relevant age groups to be included in one single line.

(3) When several growth curves are drawn (reflecting the production of several broods per year) the various growth curves should have the same shape, and vary only as to their origin.

(4) The scale of the ordinate (length) should start at zero, thus allowing approximate spawning periods to be identified.

(5) Each growth curve must interconnect several peaks. The more peaks a curve interconnects, the more likely it is to depict the actual growth of the population.

1/ When several years' worth of data are available, repeating the sample(s) over and over is obviously superfluous

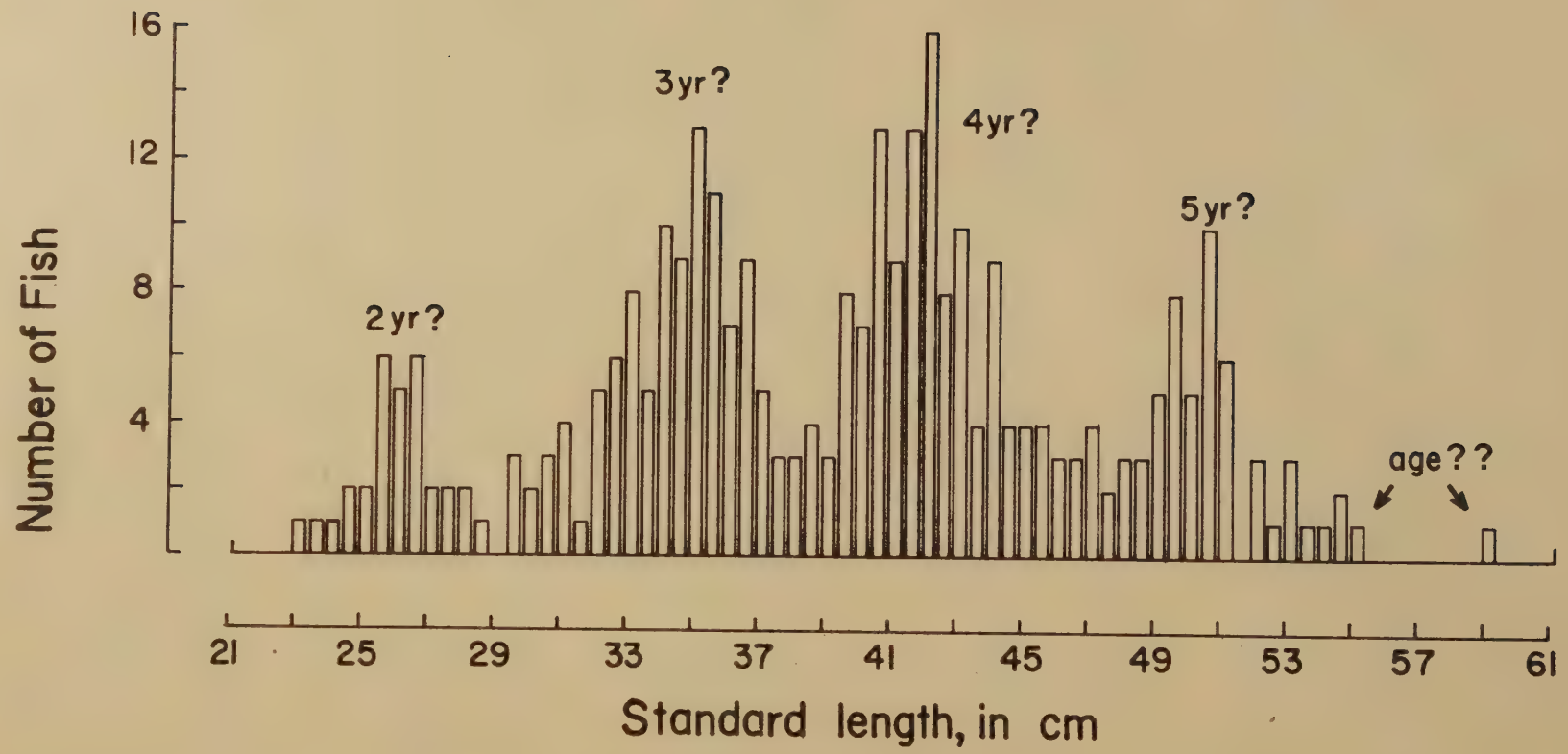

Figure 3 Length-frequency data on the coral trout (*Plectropomus leopardus*) obtained by Goeden (1978) from Heron Island (Great Barrier Reef, Australia) in October 1977. The "ages" are from Goeden, with question marks added. N = 319

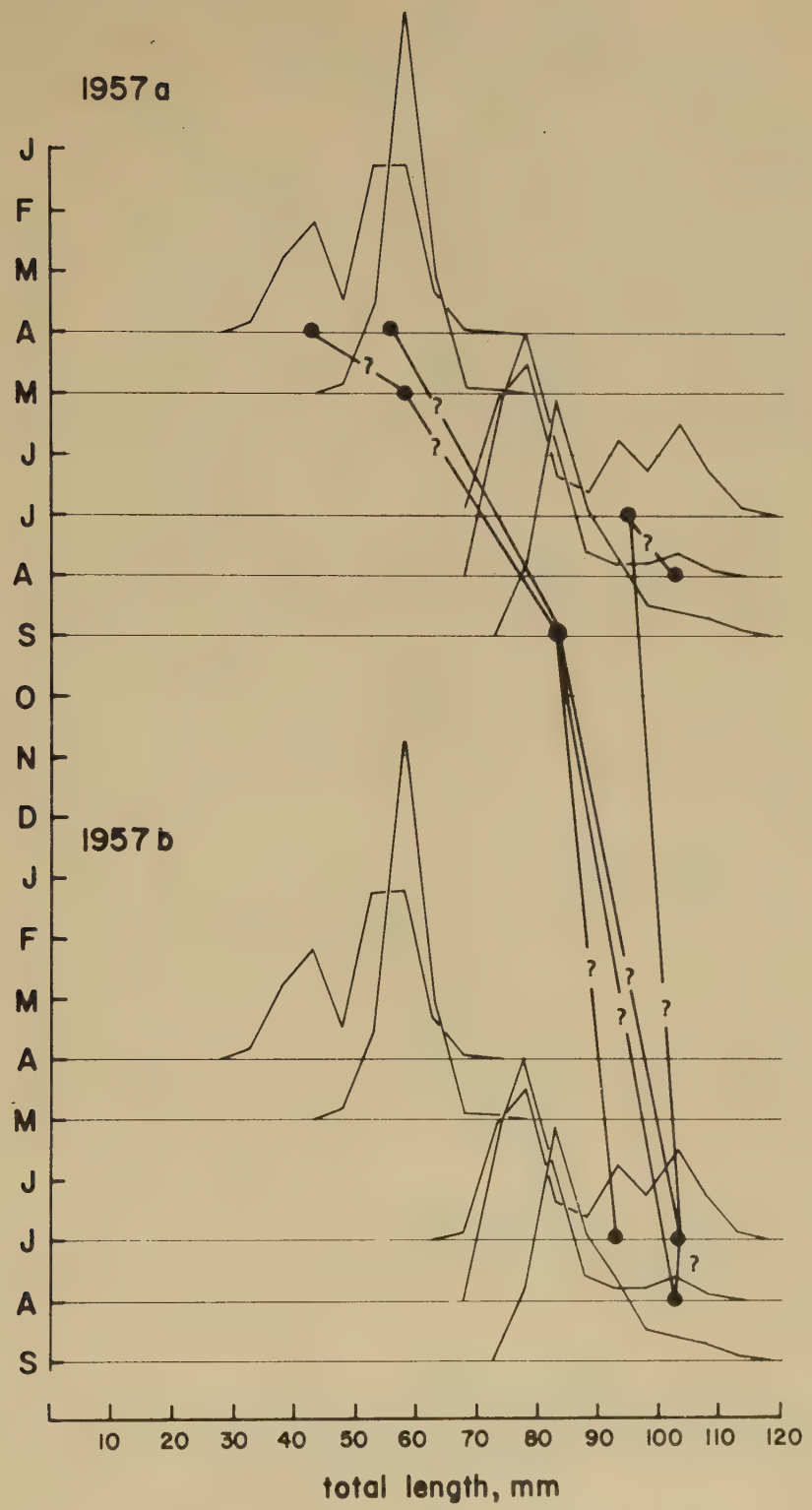

Figure 4 Showing that there are several options for connecting peaks when using the "modal class progression analysis". Based on data of Balan (1967), for *Leiognathus bindus* caught in 1957 off Calicut, India. For numbers included in each sample see Figure 10

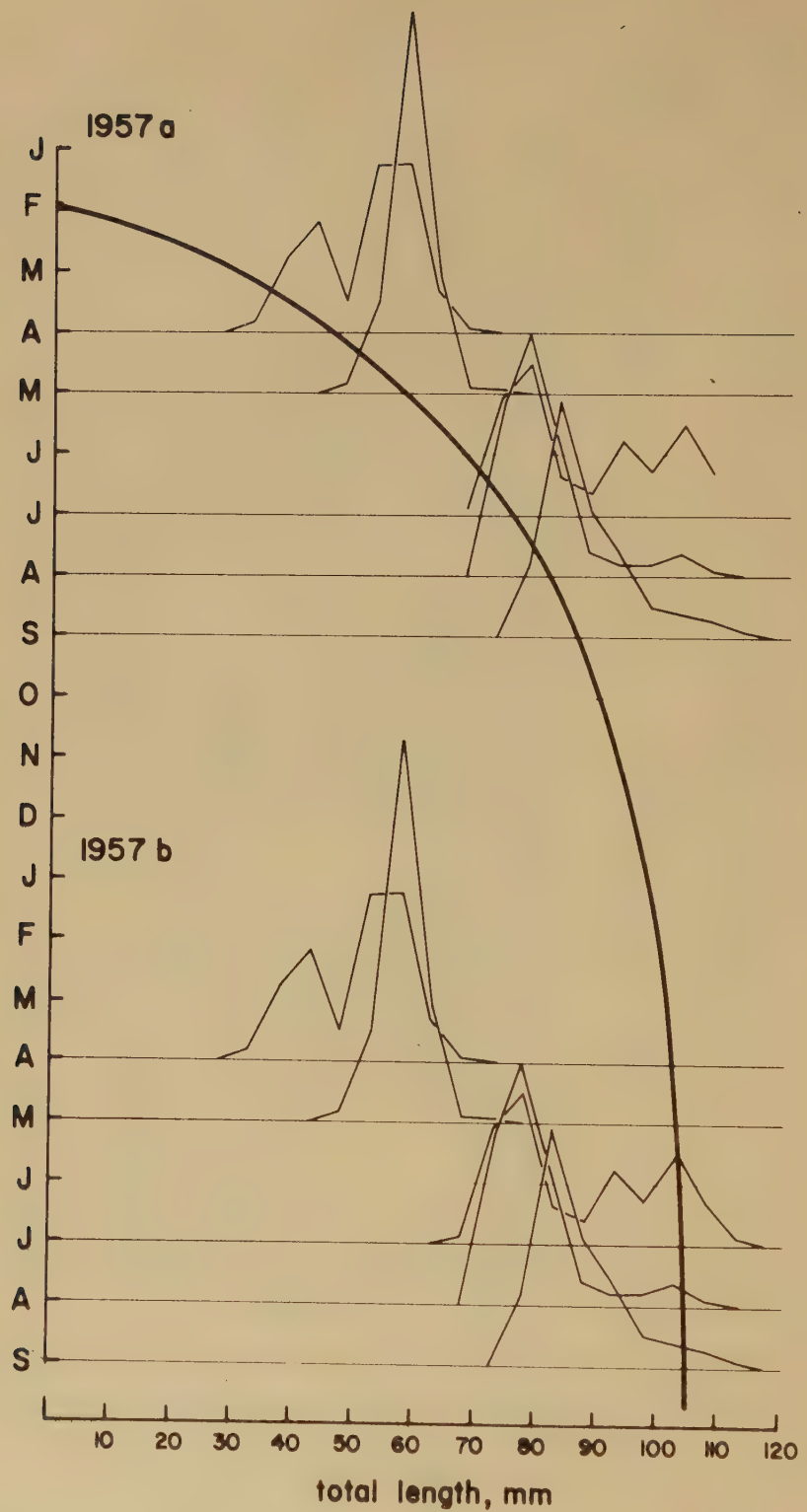

Figure 5 Showing how drawing a single, continuous growth curve onto a series of samples sequentially arranged in time limits the number of available options for connecting peaks to only one single, most probable option. Note repetition of sample sequence over two "years". Based on data of Balan (1967), for *Leiognathus bindus* caught in 1957 off Calicut, India. For numbers included in each sample see Figure 10

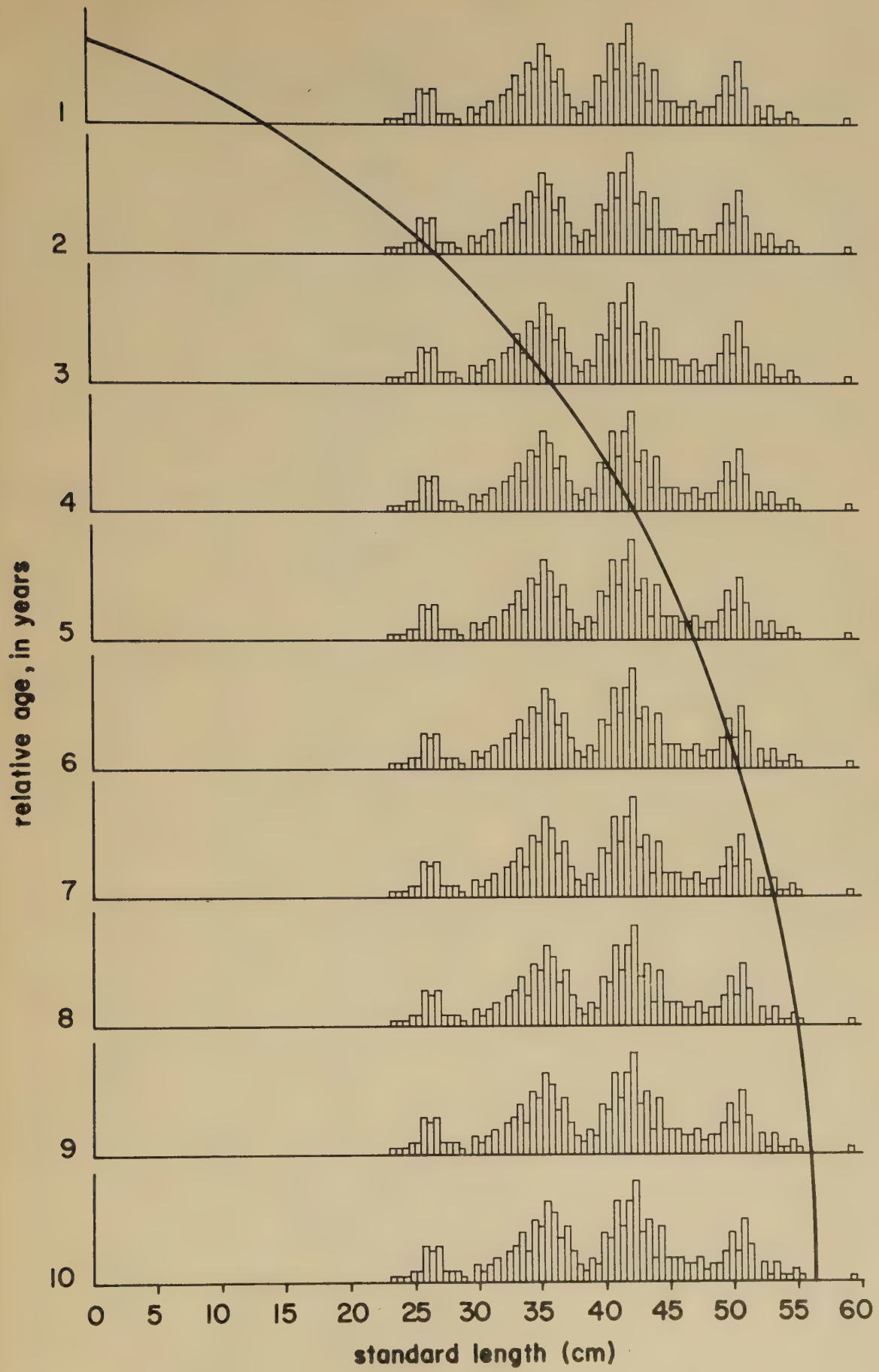

Figure 6 Showing how the single sample of Figure 3 when repeated over and over along the time axis can be fitted by eye, with a single continuous and smooth growth curve. Note that from "age" 4 on, the curves provide an interpretation of the growth of *Plectropomus leopardus* different from that given by Goeden, 1978 (see Figure 3 and text)

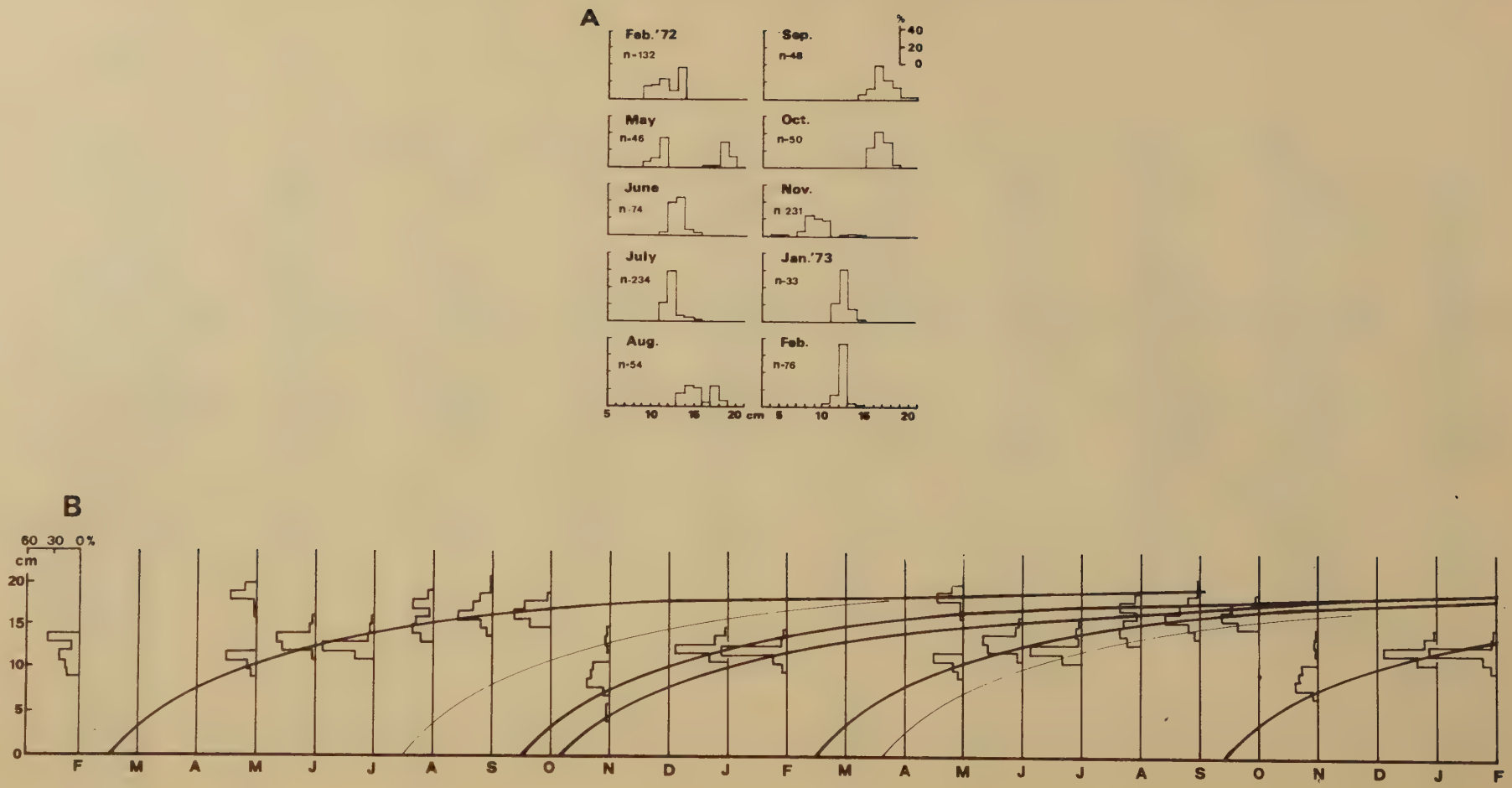

Figure 7 A - Length-frequency data on *Sardinella sirm* as presented by their original authors (Burhanuddin *et al.*, 1974)
B - The same data, redrawn according to the integrated method (see text)

(6) The modal lengths corresponding to various ages (starting from an arbitrary age) can be read off the curve at regular time intervals, and may be then used to determine the growth parameters with a method as simple as a Ford-Walford Plot (see further below).

It is my experience that length-frequency data published in the literature or available in the form of unpublished manuscripts are generally underutilized, especially in the tropics. More often than not, no attempt is made to extract growth parameters from length-frequency data even when these are eminently suitable to such treatment, as shown in Figures 4 to 7. Also, I believe that the danger of obtaining completely erroneous growth parameters from length-frequency data is generally overstated, at least as far as small tropical fishes are concerned. In fact, the integrated method, as presented here makes it quite hard to trace "wrong" growth curves, and the parameters obtained from such curves will describe the growth of at least the exploited part of a population well enough for most purposes.

Exercise: Plot length-frequency data of your own (or taken from the literature), trace most probable growth curve(s) according to the integrated method and read off the lengths at monthly intervals.

Methods for Obtaining Growth Parameters from Length-at-Age Data

The method most commonly used for estimating the parameters L_∞ and K of the VBGF is the "Ford-Walford Plot" which essentially consists of a rewritten version of the VBGF of the form

$$L_{t+1} = a + bL_t \qquad (10)$$

where $L_\infty = \frac{a}{1-b}$ (11a)

and $K = -\log_e b$ (11b)

and where L_t and L_{t+1} pertain to lengths separated by a constant time interval (1 = year, month, week, etc.). Table 3 below shows how length-at-age data should be rearranged for use with a Ford-Walford Plot.

Table 3

Length-at-age data on the Atlantic yellowfin (*Thunnus albacares*)[1/] off Senegal for use with a Ford-Walford Plot

Age (y)	L (cm)	Rearrangement for Ford-Walford Plot	
1	35	L_t (x)	L_{t+1} (y)
2	55	35	55
3	75	55	75
4	90	75	90
5	105	90	105
6	115	105	115

1/ From Postel (1955)

The data provide estimates of a = 26.17 and b = 0.859, from which, using Equations 11a and 11b, we estimate L_∞ = 186 and K = 0.152.

Exercise: (a) Draw a Ford-Walford Plot with the data of Table 3 and estimate L_∞ from the intersection of the Plot with the line $L_{t+1} = Lt$

(b) Estimate the growth parameters L_∞ and K for *Plectropomus leopardus*, *Leiognathus bindus* and *Sardinella sirm* using the growth curves in Figures 5, 6 and 7, Ford-Waldford Plots and the regression technique for estimating the a and b values.

An Alternative Method for Estimating Growth Parameters

When continuous growth lines (such as in Figures 5, 6 and 7) cannot be traced, or when only tagging and recapture data are available, the growth data obtained cannot be used in conjunction with a Ford-Walford Plot. In such cases, the "Gulland and Holt Plot" may be used, which provides estimates of L_∞ and K through the feature that

$$\frac{L_2 - L_1}{t_2 - t_1} \simeq a - K \cdot \bar{L} \qquad (12)$$

where $\bar{L} = \frac{L_1 + L_2}{2}$, and where L_1 and L_2 are successive lengths, pertaining to times t_1 and t_2, respectively.

Table 4 and Figure 8 give an example of data of this kind, which are typically obtained from tagging studies. The method, however, also allows for the use of size-at-age data, at equal or unequal intervals granted the values of $(t_2 - t_1)$ stay small in relation to the longevity of the fish (Gulland and Holt, 1959).

Equation 12 it will be noted, has the form of a linear regression with

$$x = \bar{L} \qquad (13a)$$

and $$y = \frac{L_2 - L_1}{t_2 - t_1} \qquad (13b)$$

the intercept (a) and slope (b), which provide values of K and L_∞ through the relationships

$$K = -b \qquad (14a)$$

and $$L_\infty = \frac{a}{k} \qquad (14b)$$

At times, it will happen that the method does not provide reasonable parameter estimates. This will occur most often when the $\bar{L}$ data are too close to each other (Figure 9). In such a case, a set value of the asymptotic length may be used in connexion with the means of all $\bar{L}$ values $(\bar{x})$ and of all $\frac{L_2 - L_1}{t_2 - t_1}$ values $(\bar{y})$ to obtain an estimate of K through

$$K = \frac{\bar{y}}{(L_{(\infty)} - \bar{x})} \qquad (15)$$

This method, called "forced" Gulland and Holt Plot, allows in fact for a rough first estimate of K even when only <u>one</u> pair of x and y values are available.

Table 4

Length at tagging (L_1), length at recapture (L_2) and time at large in tagged ocean surgeon fish (*Acanthurus bahianus*) from the Virgin Islands[1/]

Number	L_1 (cm)	L_2	Days out
1	9.7	10.2	53
2	10.5	10.9	33
3	10.9	11.8	108
4	11.1	12.0	102
5	12.4	15.5	272
6	12.8	13.6	48
7	14.0	14.3	53
8	16.1	16.4	73
9	16.3	16.5	63
10	17.0	17.2	106
11	17.7	18.0	111

1/ Selected from Table 3 of Randall (1962). Data included pertain to fishes which grew at least 2 mm while at large, which accounts for small measurement errors and cases of no-growth due to tagging wounds.

Table 5

Length at tagging (L_1), length at recapture (L_2) and days at large of tagged queen parrot fish (*Scarus vetula*) from the Virgin Islands[1/]

Number	L_1 (cm)	L_2	Days out	$\bar{L}$	cm/day
1	14.0	16.9	48	15.45	0.0604
2	20.8	27.6	189	24.2	0.0360
3	24.8	26.5	48	25.65	0.0354
			means: $\bar{x}$ = 21.77	$\bar{y}$ = 0.0439	

1/ Adapted from Table 17 of Randall (1962)

The use of a set value for the asymptotic length is here coded $L_{(\infty)}$, to distinguish it from values of L_∞ obtained from the growth data themselves. Reasonable values of $L_{(\infty)}$ can generally be obtained from the empirical relationship

$$\frac{L_{max}}{0.95} \approx L_{(\infty)} \qquad (16)$$

where L_{max} is the length of the largest fish reported from a well sampled stock, if at all possible, taken at a time when exploitation was still low.

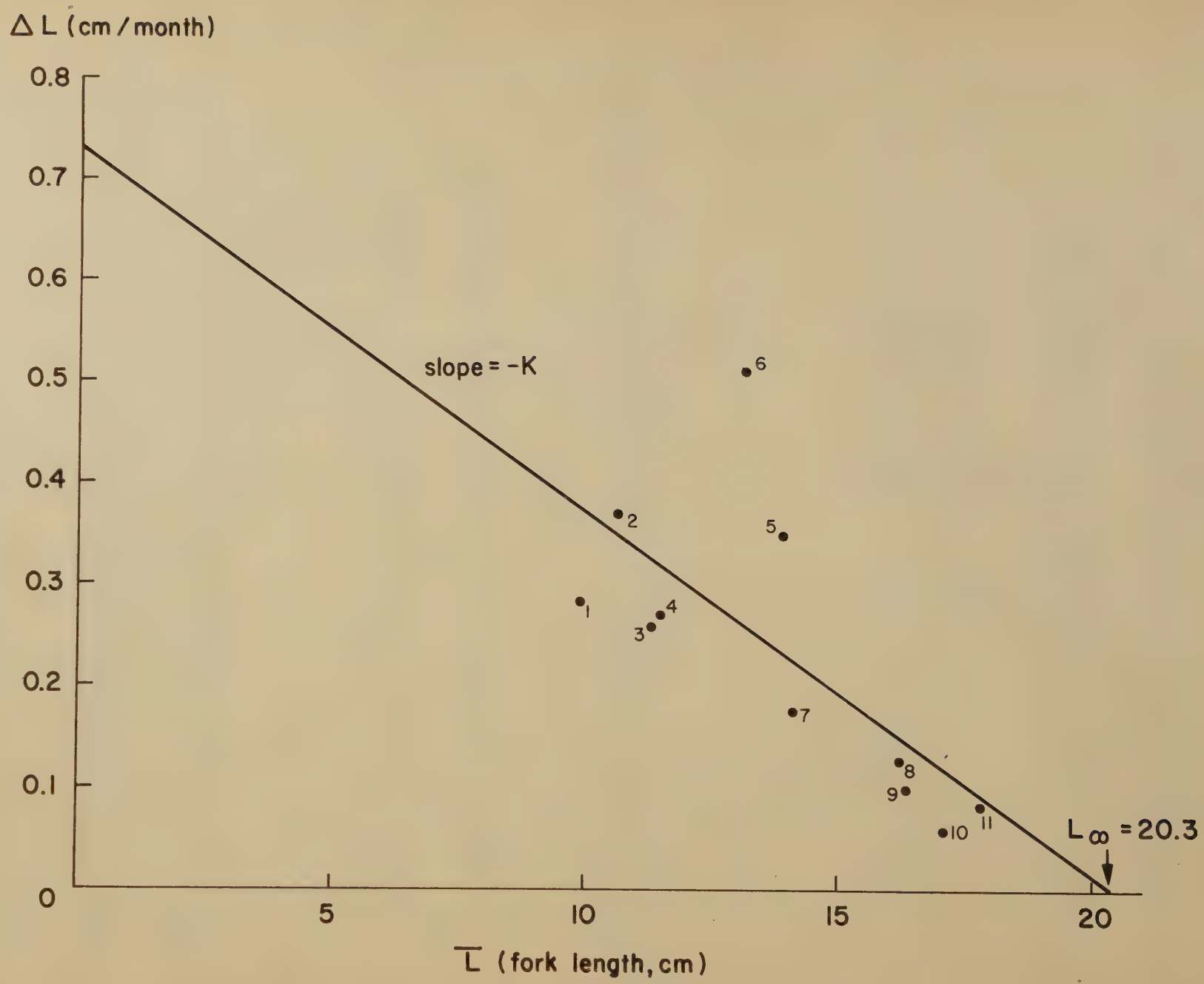

Figure 8 Showing a "Gulland and Holt Plot" of data on the ocean surgeon fish (*Acanthurus bahianus*) (see Table 4 and text)

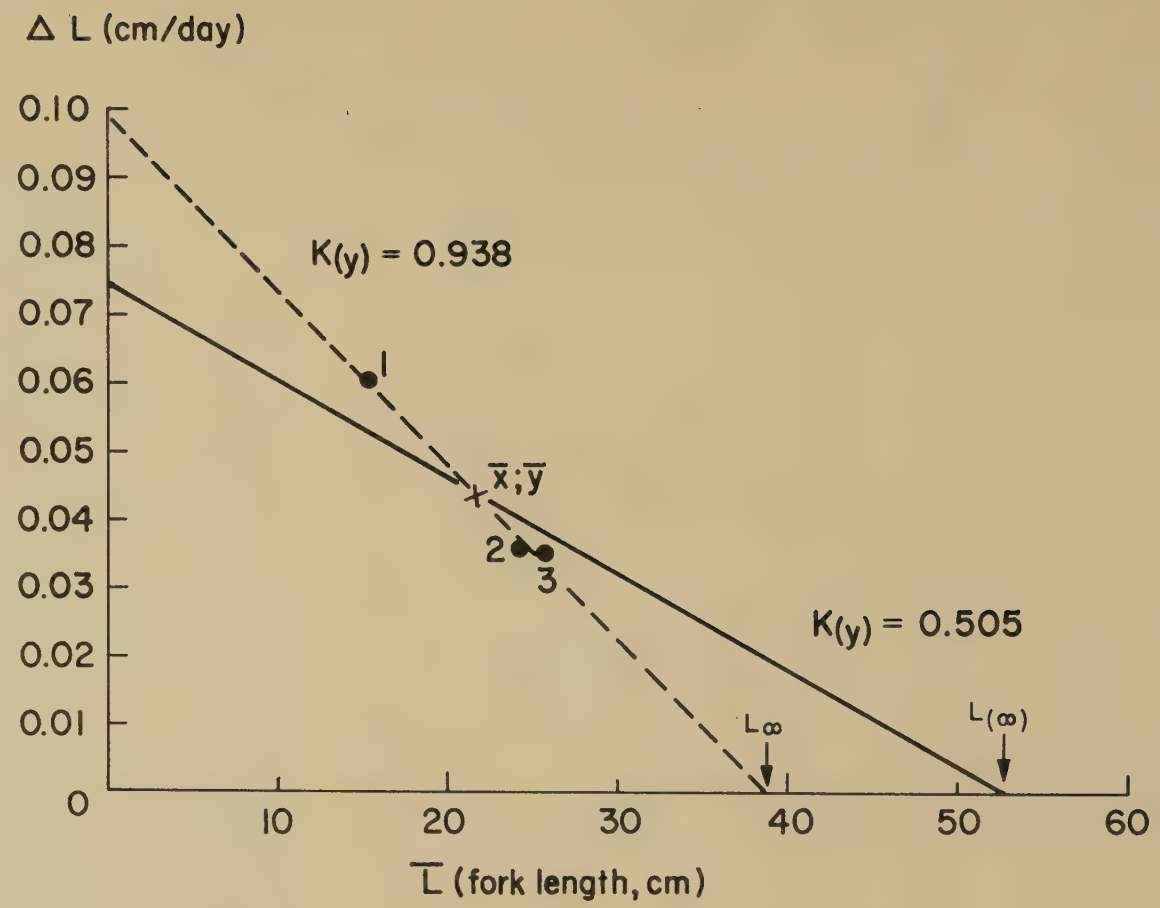

Figure 9 Showing a "Gulland and Holt Plot" and a "forced Gulland and Holt Plot" for the queen parrot fish (*Scarus vetula*). Based on data of Table 5; see text

The Gulland and Holt Plot does not allow for the estimation of the third parameter of the VBGF, t_o. When this parameter is necessary (e.g., when a certain age is to be attributed to a certain length) a rough estimate of t_o may be obtained from the empirical relationship.

$$\log_{10}(-t_o) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K \qquad (17)$$

derived in Pauly (1979a) from 153 triplets of t_o, L_∞ (total length, in cm) and K (annual basis) selected from my compilation of length growth parameters (Pauly, 1978a) such as to cover a wide diversity of taxa and size.

Exercise: Calculate values of L_∞, K from the data of Table 6 (see Figure 10) on *Leiognathus bindus* for the years 1956, 1957 and 1958 using the Gulland and Holt Plot and obtain a rough estimate of t_o, using Equation 17.

Table 6

Length increment per month (h) and mean length[1/] ($\bar{L}$) for growth segment (1-13) linking modal classes in *Leiognathus bindus* (1956-1958)

Segment number	h	$\bar{L}$	Segment number	h	$\bar{L}$
1	0.50	9.0	7	1.00	6.7
2	0.50	9.4	8	0.50	8.4
3	1.23	7.4	9	0.50	8.0
4	1.00	9.7	10	0.50	10.0
5	0.30	10.4	11	0.50	9.2
6	1.50	5.0	12	1.00	6.2
			13	0.50	7.7

1/ Total length

4. METHODS FOR ESTIMATING TOTAL, FISHING AND NATURAL MORTALITIES

Introduction

In fishery biology, the most useful manner of expressing the decay (=decrease) of an age group of fishes through time is by means of exponential rates. These rates, of which three are normally defined, are given in the following two expressions:

$$N_t = N_o \cdot e^{-Zt} \qquad (18)$$

where N_o is the (initial) number of fishes at time t = o, and N_t is the number of remaining fishes at the end of time t, Z being the instantaneous rate of total mortality. An advantage of instantaneous rates is that they can be added or subtracted. Thus we have

$$Z = M + F \qquad (19)$$

where M is the instantaneous rate of natural mortality and F the instantaneous rate of fishing mortality (see Figure 11). Obviously, when

$$F = 0 \text{ then, } Z = M \qquad (20)$$

which means that natural and total mortality have the same value when there is no fishing (in an unexploited stock).

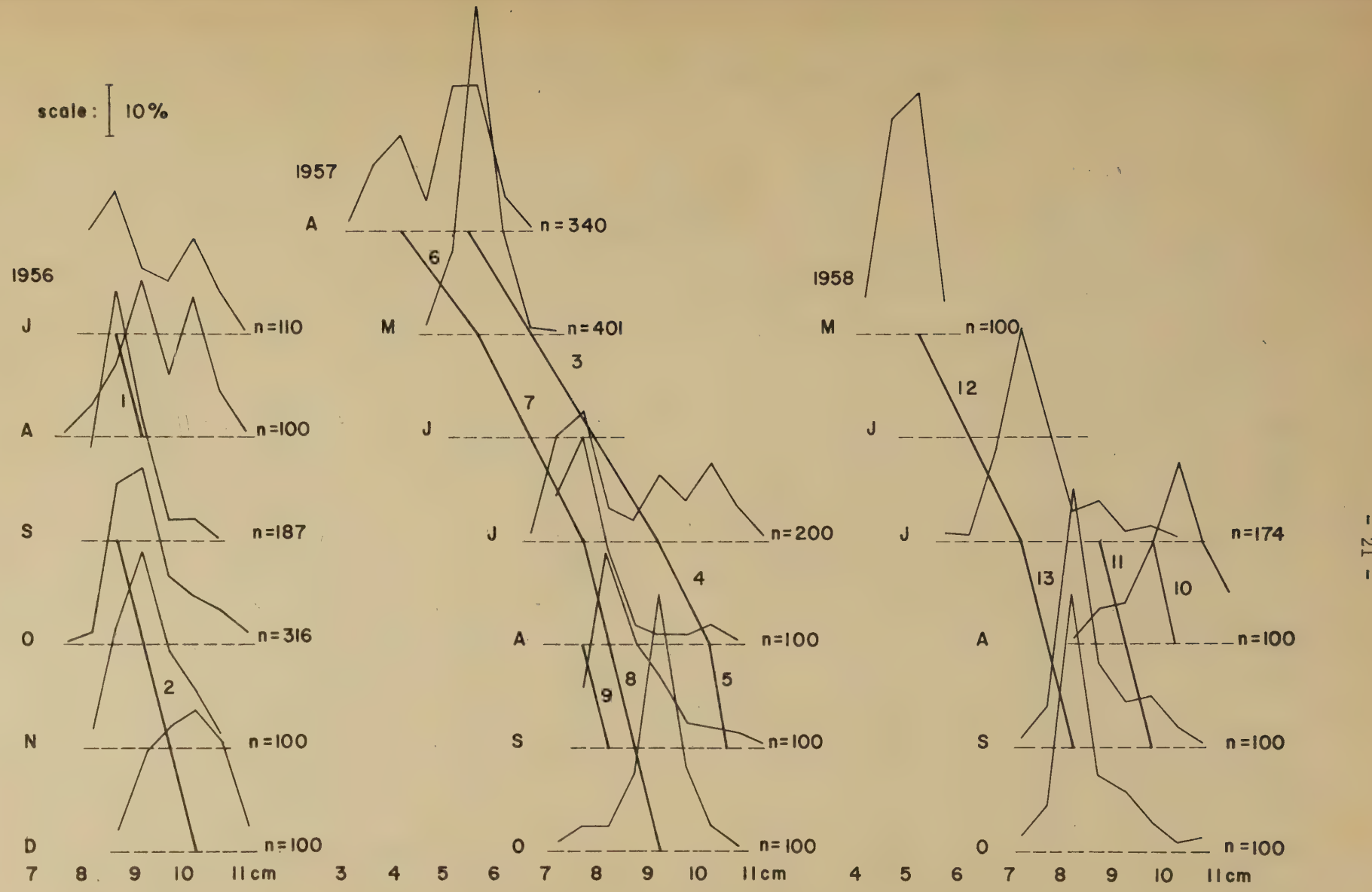

Figure 10 Length-frequency data on the slipmouth *Leiognathus bindus* caught off Calicut, India in years 1956, 1957 and 1958, with suggested "growth segments" for use with a Gulland and Holt Plot (see Table 6 and text). Based on data of Balan 1967

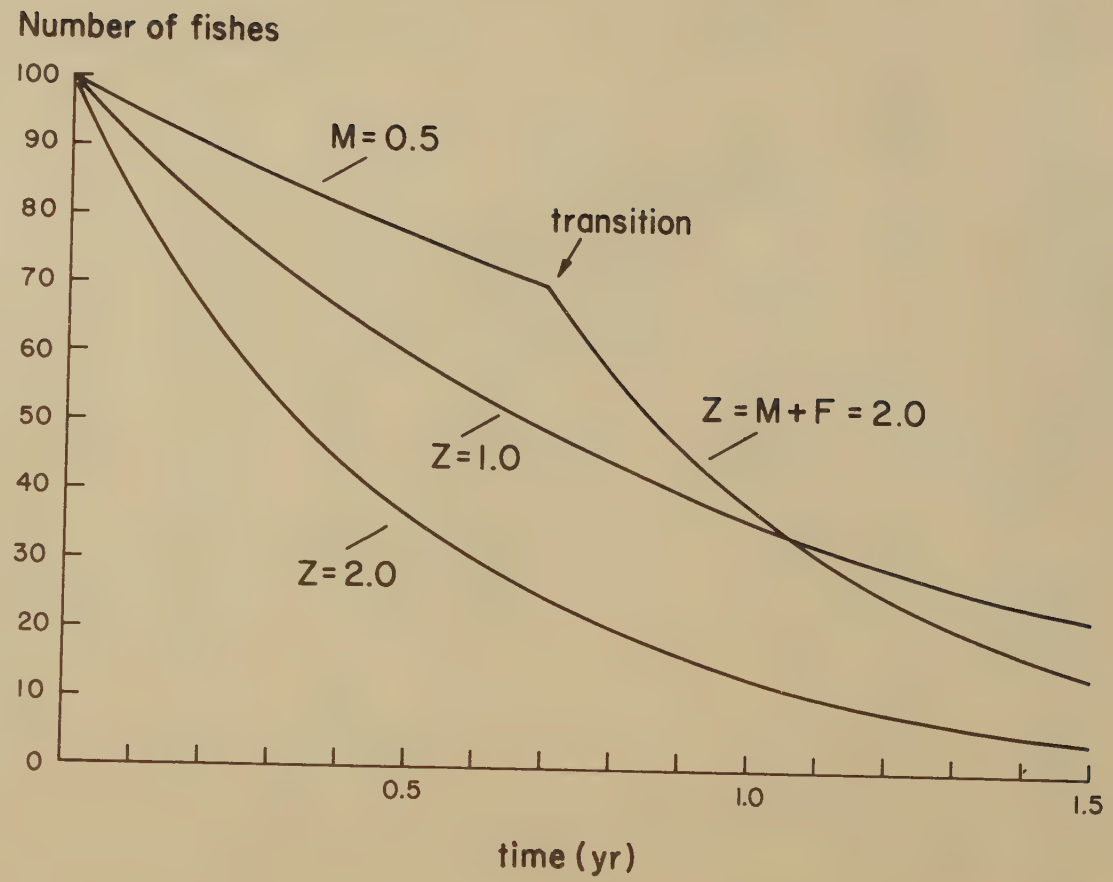

Figure 11 Showing the decrease of a cohort of fishes, over time, starting with 100 fishes at age 0, with 3 levels of mortality

The fishery biologist, as far as mortalities are concerned, has two main jobs:

(a) To estimate the value of Z;
(b) To split - where appropriate - an estimated value of Z into its component parts M and F.

Estimating Total Mortality

Total mortality from the mean size in the catch

(a) When a large number of length-frequency data have been obtained from a given stock, by a given gear, Z can be estimated from the mean length ($\bar{L}$) in the catch from a given population by means of

$$Z = \frac{K\ (L_\infty - \bar{L})}{\bar{L} - L'} \qquad (21)$$

Where L_∞ and K are parameters of the von Bertalanffy growth equations, $\bar{L}$ is the mean length in the catch, and " L' is the smallest length of animals that are fully represented in catch samples" (Beverton and Holt 1956).

(b) Another equation which can be used to estimate Z from the mean length in the catch is

$$Z = \frac{n \cdot K}{(n+1) \cdot \log_e \left(\frac{L_\infty - L'}{L_\infty - \bar{L}}\right)} \qquad (22)$$

where L_∞, $\bar{L}$, L' and K are defined above while n is the number of fishes used for the estimation of $\bar{L}$ (based on Ssentengo and Larkin 1973). It will be noted that when n is large, the term n/n+1 tends toward unity and hence can be neglected.1/

(c) The equation corresponding to Expression 22 is for weight (when growth is isometric):

$$Z = \frac{n \cdot K}{(n+1)\ \log_e \left(\frac{\sqrt[3]{W_\infty} - \sqrt[3]{W'}}{\sqrt[3]{W_\infty} - \sqrt[3]{\bar{W}}}\right)} \qquad (23)$$

where W_∞ and K are parameters of the von Bertalanffy growth function for weight growth, which has the form

$$W_t = W_\infty\ (1-e^{-K\ (t-t_o)})^3 \qquad (24)$$

with $\bar{W}$ and W' being the weight corresponding to $\bar{L}$ and L' as obtained (along with W_∞) from a conversion from length to weight, by means of the appropriate length-weight relationship.

Equation 24 is particularly useful in that it is quite easy to weigh a catch and to divide it by the number of fish to obtain $\bar{W}$.

1/ See footnote page 29.

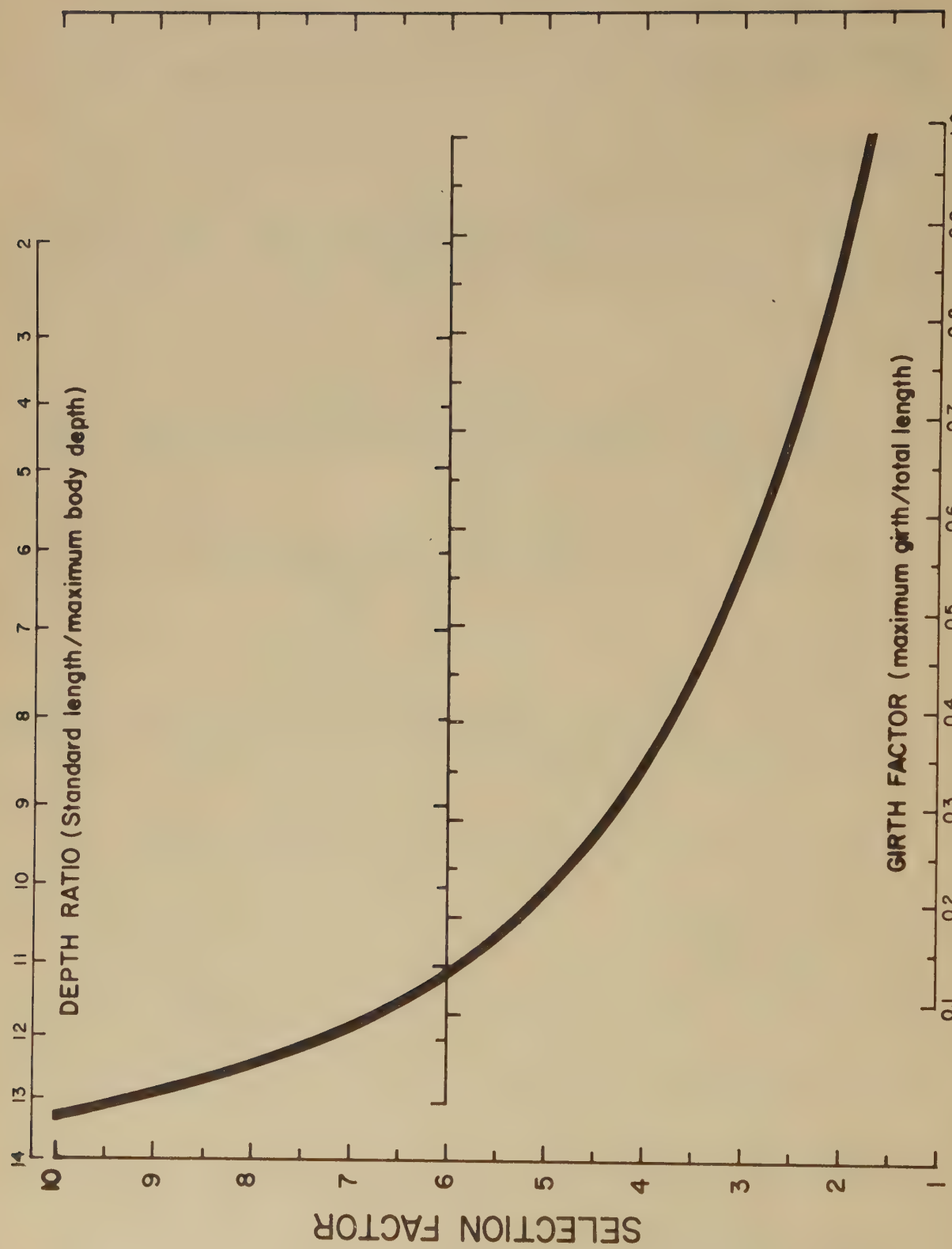

Figure 12 Nomogram for the estimation of the selection factors of fishes from measurements of their body proportions. Based on data in Sinoda *et al.*, 1979 and Meemeskul (1979). Original. (Note: all selection factors estimated by means of this nomogram refer to total length. Hence: SF · mesh size = L_c (total length))

Table 7

Estimation of values of Z by 2 methods based on data for *Selaroides leptolepis* in the Gulf of Thailand given in Boonyubol and Hongskul (1978)

Year	Effort	n	$\bar{L}$	Z_1	Z_2
1966	2.08	4 733	13.25	2.41	2.95
1967	2.08	11 902	13.01	2.69	3.24
1968	3.50	12 503	12.99	2.72	3.27
1969	3.60	9 060	13.07	2.62	3.16
1970	3.80	8 132	12.37	3.73	4.29
1972	7.19	3 635	12.30	3.88	4.44
1973	9.94	10 510	12.01	4.61	5.14
1974	6.06	7 960	12.60	3.30	3.85
$\bar{x}$	4.87		12.70	3.25	3.79

Constants: $L_\infty = 20.0$; $K = 1.16$; $L_c = 10.0$ (Z_1 = equation 21; Z_2 = equation 22)

A parameter closely related to L' (see above for definition) is the mean length at first capture (L_c), or the length at which 50% of the animals sampled are retained by the gear.

L_c is normally estimated from selection experiments (see Gulland 1969) which, however, are rather time and resource consuming. To facilitate estimation of L_c, a figure is therefore included which allows for values of L_c to be obtained from attributes of fish that are very easy to obtain, such as the length/depth ratio, or the "girth factor" of fishes (Figure 12).

Figure 12, however, does not allow for a direct estimation of L_c. Rather, once the length/depth ratio or the girth factor have been estimated, Figure 12 is used to estimate a selection factor (SF) such that

$$L_c = SF \cdot \text{mesh size (of cod end)}^{1} \qquad (25)$$

The parameter L_c is used in stock assessment in a number of models, notably that of Beverton and Holt (1966). In cases where "knife-edge" selection occurs (see Beverton and Holt 1966, or Gulland 1969), $L_c = L'$; generally however, $L' > L_c$.

1/ When the sampling gear is a trawl

Estimating Z by Means of a Catch Curve

Another method of estimating Z consists of sampling a multi-aged population of fishes, then plotting the natural logarithm ($\log_e$) of the number of fishes in the sample (N) against their respective age (t) or

$$\log_e N = a + bt \qquad (26)$$

where the value of b, with sign changed, provides an estimate of Z.

Several requirements must be met for the values of -b to be a good estimator of Z. Among these, we may mention:

(a) Only those values of $\log_e N$ must be included which pertain to age group of fishes fully vulnerable to the gear in question (among other things, the fish must be larger than L' as defined above): This corresponds to using only the "descending part" of a catch curve (see Figure 13).

(b) Recruitment must have been constant within the period covered, or have varied in a random fashion only.

When suitable length-frequency samples are available, a catch curve may also be constructed through previous conversion from length to age by means of a set of growth parameters. Here, however, care must be taken not to include fish whose size is close to that of their asymptotic size, as this may result in their age being grossly over-estimated. This latter feature incidentally makes it imperative that a scatterdiagram be drawn in order to properly identify the section of the catch curve which can be used to estimate Z (Figure 13). It will be noted, also, that since Z is equal to the slope (with sign changed) of the catch curve the real age - which requires an estimate of t_o - can be here replaced by relative age, i.e., by setting $t_o = 0$ (Table 8, Figure 13).

Also, when converting a length-frequency sample to a catch curve, a problem must be considered which doesn't occur when fish have been aged individually. This problem is due to the fact that length growth not being linear, it takes an older fish longer than a younger fish to grow through a given size-group. Put another way, among bigger fish, a given magnitude of size interval (e.g., a 1-cm length group) will contain more age groups than among small fish.

Compensating for this "piling-up" effect is, however, quite straightforward and can be achieved, e.g. by rewriting equation (26) as

$$\log_e (N/\Delta t) = a + bt \qquad ...(26a)$$

where Δt is the time needed to grow from the lower (t_1) to the upper (t_2) limit of a given length class, while t is the relative age corresponding to the midrange of the length class in question. The procedure to convert a length-frequency to a length-structured catch curve is illustrated in Table 8 and Fig. 13.

Table 8

Data for the construction of a catch curve for the yellow striped goatfish *Upeneus vittatus* from Manila Bay, the Philippines 1/

Class limits Lower 2/	Class limits Upper 2/	Mid-range 2/	N	t_1 3/	t_2 3/	Δt	Adjusted number per length class $\log_e \frac{N}{\Delta t}$	Mean relative age t 3/	Remarks
6.000	6.999	6.5	3	0.510	0.612	0.102	3.38	0.56	
7.000	7.999	7.5	143	0.612	0.720	0.109	7.18	0.67	
8.000	8.999	8.5	271	0.721	0.837	0.116	7.76	0.78	
9.000	9.999	9.5	318	0.837	0.961	0.125	7.84	0.90	Not used, ascending part of curve
10.000	10.999	10.5	416	0.961	1.096	0.134	8.04	1.03	
11.000	11.999	11.5	488	1.096	1.242	0.146	8.11	1.17	
12.000	12.999	12.5	614	1.242	1.402	0.160	8.25	1.32	
13.000	13.999	13.5	613	1.402	1.579	0.177	8.15	1.49	
14.000	14.999	14.5	493	1.579	1.776	0.197	7.83	1.67	
15.000	15.999	15.5	278	1.776	1.999	0.223	7.13	1.88	
16.000	16.999	16.5	93	2.000	2.257	0.257	5.89	2.12	Portion used for estimating Z
17.000	17.999	17.5	73	2.257	2.560	0.303	5.48	2.40	
18.000	18.999	18.5	7	2.560	2.930	0.370	2.94	2.74	
19.000	19.999	19.5	2	2.930	3.404	0.473	1.44	3.15	
20.000	20.999	20.5	2	3.404	4.063	0.659	1.11	3.70	
21.000	21.999	21.5	0	4.064	5.159	1.094	-	4.53	Not used, too close to L_∞
22.000	22.999	22.5	1	5.160	9.208	4.047	-1.40	6.19	
23.000	23.999	23.5	1	-	-	-	-		

1/ From Ziegler (1979) who also gives: L_∞ = 23.1 and K = 0.59 and T = 28°C

2/ Total length, in cm

3/ Computed by means of equation 32, with t_o = 0

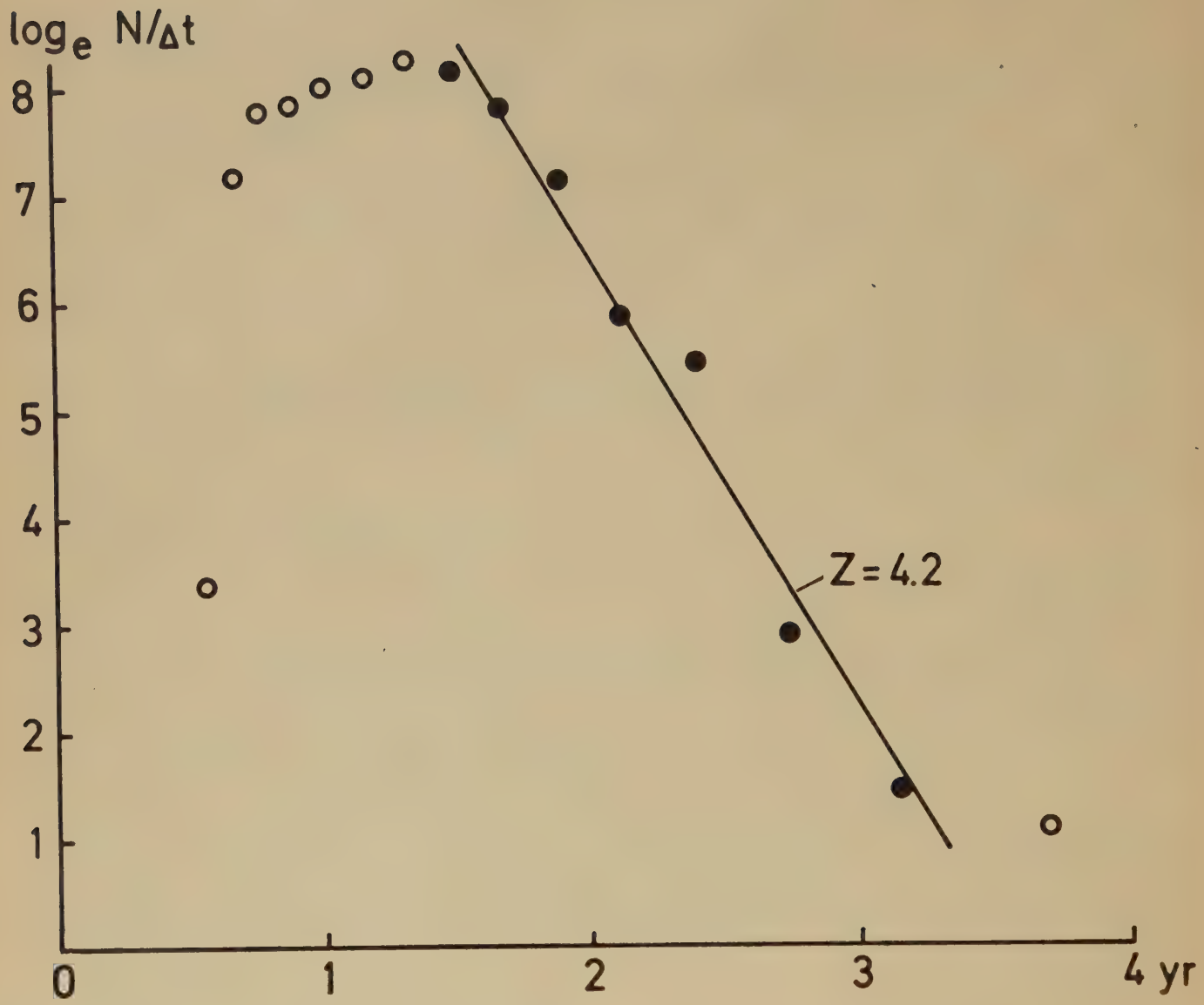

Figure 13. A catch curve based on length converted to age, and corrected for the time needed for the fish to grow through the size classes (see text). Based on the data of Table 8, the regression equation is $\log_e(N/\Delta t) = 14.8 - 4.19t$, ($r = 0.988$), which provides an estimate of $Z = 4.2$.

Splitting Z into M and F

Splitting Z into M and F by means of a plot of Z on effort

When values of Z are available for several years pertaining to different annual values of effort (f), the value of M can be calculated from

$$Z = M + qf \tag{27}$$

where q is the "catchability coefficient", which relates f and fishing mortality (F) through

$$F = q \cdot f \tag{28}$$

Thus, a series of Z (mean annual) values can be plotted against their corresponding values of f and a straight line fitted to the points by means of linear regression technique. This results in a regression line with the equation

$$y = a + bx \tag{29}$$

where Z = y and x = f, the slope (b) of which provides an estimate of the catchability coefficient q while the intercept value (a) is an estimate of M (see Figure 14) in which values of Z based on Equations 21 and 22 have been plotted.[1/]

Splitting Z into M and F by means of an independent estimate of M

When only one value of Z is available, or when the available values of Z and f cover too small a range of Z and f values for reasonable values of M and q to be obtained, the catchability coefficient (q) may be estimated through

$$q = \frac{\overline{Z} - M}{\overline{f}} \tag{30}$$

where $\overline{Z}$ is the mean of the available values of Z (or a single value of Z) and $\overline{f}$ is the mean of the values of f (or a single value of f), M being an independent estimate of natural mortality (see Table 7 and Figure 14).

Method for Obtaining Independent Estimate of M

It has been demonstrated by various authors that the value of the parameter K of the VBGF in fishes is closely linked with their longevity. This can be demonstrated on the basis of the observation that, generally, in nature, the oldest fishes of a stock grow to reach about 95 percent of their asymptotic length (Taylor, 1962; Beverton, 1963). Thus when we have

$$L_t = L_\infty(1-e^{-K(t-t_o)}) \tag{31}$$

we also have

$$t - t_o = \frac{\log_e\left(1 \frac{L_t}{L_\infty}\right)}{-K} \tag{32}$$

1/ It will be noted that equation 22 produces estimates of Z which are higher than those obtained using equation 21; Mr. P. Sparre (Danish Institute for Fishery and Marine Research) suggests (pers.comm.) that equation 22 is biased upward.

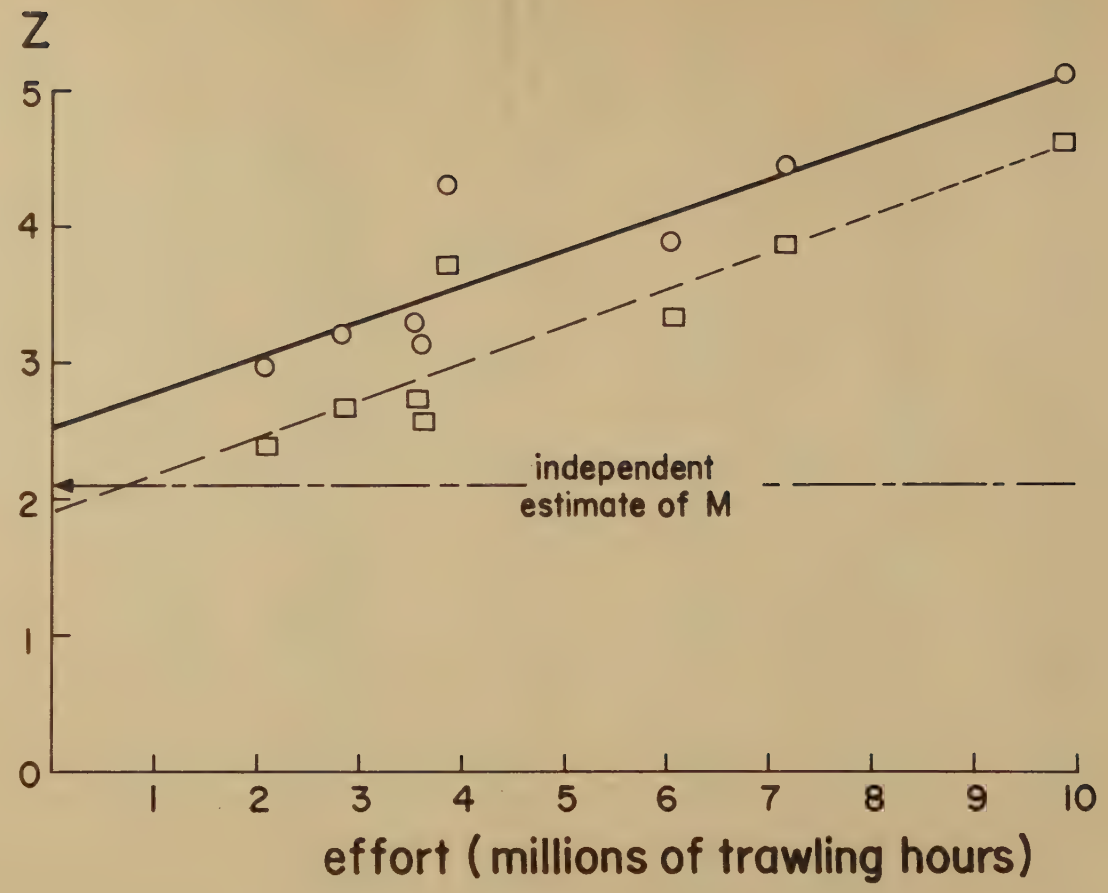

Figure 14 Plots of total mortality (Z) on effort (f) to estimate natural mortality and catchability coefficient in *Selaroides leptolepis* from the Gulf of Thailand. Based on data in Table 7. The equations are:

$Z_1 = 1.96 + 0.263f$ (squares)

$Z_2 = 2.52 + 0.263f$ (dots)

or, if we insert 95 percent of L_∞ for the oldest fish

$$t - t_o = \frac{2,9957}{-K} \qquad (33)$$

thus

$$t_{max} \approx \frac{3}{K} \qquad (34)$$

where t_{max} is the longevity of the fishes in question.

That natural mortality should, in fishes, be correlated with longevity, hence with K, seems obvious. Natural mortality should, in fishes, also correlate with size since large fishes should have, as a rule, fewer predators than small fishes.

Natural mortality in fishes can also be demonstrated to be correlated to mean environmental temperature (Pauly, 1978b, 1980a.) These various interrelationships can be expressed for length-growth data by the multiple regression

$$\log_{10}M = -0.0066-0.279 \log_{10}L_\infty + 0.6543 \log_{10}K + 0.4634 \log_{10}T \qquad (35)$$

and for weight-growth data by

$$\log_{10}M = -0.2107-0.0824 \log_{10}W_\infty + 0.6757 \log_{10}K + 0.4687 \log_{10}T \qquad (36)$$

Where M is the natural mortality in a given stock, L_∞ (total length in cm) and W_∞ (live weight in g) being the asymptotic size of the fishes of that stock, and K their growth coefficient. The value of T, finally, is the annual mean temperature (in ^oC) of the water in which the stock in question lives, as obtained, e.g., from an oceanographic atlas.

These two regressions were derived from 175 sets of L_∞ (or W_∞), K, T, and M values, obtained from a survey of the pertinent literature (Pauly, 1980a) and apply, in this form, to temperatures ranging from 5^o to 30^oC, and provide useful fish estimates of M, which should, of course, be confirmed where possible by analyses on the individual species in question.

Although Equations 35 and 36 generally give reasonable estimates of M for about any set of growth parameters and temperature value, there is a group of tropical fishes in which the estimates may be biased, namely the strongly schooling pelagic fishes - especially the Clupeidae - the natural mortality of which is generally overestimated by these equations. Thus, in their case, it might be appropriate to reduce the estimate of M somehow, e.g., by multiplying it by 0.8.

Assessing the State of a Stock from its Mortality Rates Alone

Once values of F and M are available, an exploitation ratio (E) may be computed from

$$E = \frac{F}{F + M} \qquad (37)$$

which allows one to (roughly) assess if a stock is overfished or not, on the assumption that the optimal value of E (E_{opt}) is about equal to 0.5, the use of $E \approx 0.5$ as optimal value for the exploitation ratio itself resting on the assumption that sustainable yield is optimized when $F \approx M$ (Gulland, 1971).

Exercise: (a) Depict the decay of a cohort of fishes (N_o = 100 000) with M = 0.5 and F = 1.0 with exploitation starting at age 0.5 year.

(b) Calculate values of Z from the data in Table 10 using Equations 21 and 22, and use these estimates to obtain a value of M and q by means of Expression 27.

(c) Compare the value of M obtained in b with a value of M obtained from Expression 35 using L_∞ = 29, K = 1.2 and T = 28°C.

(d) Use the data of Table 10 to draw a catch curve using Equations 26a and 32, with t_o = 0, to convert the midlength values to estimates of relative age, and estimate Z. Estimate M by means of Expression 35 and the appropriate growth parameters. Compute F and E and assess whether the stock in question is optimally exploited or not.

Table 9

Data for estimating values of Z, F and q values in *Priacanthus tayenus* from the Gulf of Thailand[1/]

Year	Effort[2/]	$\bar{L}$[3/]	n
1966	2.08	15.7	12 370
1967	2.80	15.5	14 231
1968	3.50	16.1	10 956
1969	3.60	14.9	9 738
1970	3.80	14.4	12 631
1973	9.94	12.8	9 091
1974	6.06	12.8	15 229

1/ Based on data in Boonyubol and Hongskul (1978) and SCS (1978)
2/ In million trawling hours
3/ To be used in conjunction with L_∞=29, K=1.2 and L_c=7.6

Table 10

Length-frequency data for the construction of a catch curve and the estimation of Z in the Japanese threadfin bream *Nemipterus japonicus* from Manila Bay[1/]

Class midlength[2/]	N	Class midlength[2/]		N
7.5	11	17.5		428
8.5	69	18.5		338
9.5	187	19.5		184
10.5	133	20.5		73
11.5	114	21.5		37
12.5	261	22.5		21
13.5	386	23.5		19
14.5	445	24.5		8
15.5	535	25.5	do not use	7
16.5	407	26.5	do not use	2

1/ Based on Ziegler (1979)
2/ To be used in conjunction with L_∞ = 29.2, K = 0.607 and T = 28°C; length = total length in cm

5. SOME PROBLEMS IN TROPICAL STOCK ASSESSMENT

Introduction

Stock assessment in the tropics is generally more difficult than in temperate waters. There are a large number of reasons for this, and two of them may be listed here:

- Tropical fisheries - especially demersal fisheries - often exploit a large number of species simultaneously, with the result that neither the commercial fishery nor the artisanal fisheries - even when relatively well-monitored - can be expected to provide detailed catch and catch/effort statistics on a per species basis. For this reason, it is common in tropical fisheries to treat whole species assemblages as if they were single species.

- Tropical countries generally have a relatively limited research capability - as far as fisheries research is concerned - which often leaves most of the stocks sustaining their fishery completely uninvestigated.

Despite these and other problems, the fishery biologists working in tropical countries have been traditionally expected to provide (fast) answers to pressing questions such as

- How much fish there is in a given area.
- How much should be taken annually.
- What gears should be used.
- How to accommodate various groups (e.g., of fishermen) with diverging, or even conflicting interests.
- How to manage a fishery (what specific regulatory measures, how to enforce these, etc.).

In answer to some of these needs, several models and techniques have been developed which give (at least rough) answers to these questions. This chapter aims at briefly presenting a few of the concepts involved, and to introduce some of the literature available on the subject.

Estimating Stock Sizes

Methods for estimating the stock sizes of pelagic fishes

Stock sizes of small pelagic fishes are generally estimated by means of acoustic surveys. The methodology of such surveys is outlined in more or less detailed fashion in the following texts: Forbes and Nakken (1972), Cushing (1973), Saville (1977). Results of pelagic acoustic surveys conducted in the Western Indian Ocean, south of the equator, have been reviewed in Gulland (1979, pages 5-6).

Estimating the standing stock size of large pelagic fishes such as tuna and other large scombroids is generally very difficult and the results obtained are often highly controversial (see Sharp, 1978, 1979). Earlier surveys conducted in the Western Indian Ocean have generally concentrated on relative abundance (rather than absolute stock sizes) as indicated by the spatial distribution of the catch/effort of a standard gear (Williams, 1967).

Methods for estimating the stock size of reef fishes

Strangely enough, there is at present no generally accepted standard method for estimating the standing stock sizes of reef fishes and the wide variety of methods used (involving poisoning and SCUBA divers' direct counts methods) as well as the different concepts of what actually belongs to a "reef" have led to widely differing standing stock estimates (see Russel *et al.*, 1978). This leads to the suggestion that estimates of yield per area (see below) be used, together with estimates of fishing mortality to estimate standing stock indirectly.

Thus, since we have

$$Y = F \cdot B \qquad (38)$$

which expresses the basic interrelationship between annual catch in weight or yield (Y), mean standing stock size (B) and fishing mortality (F), we also have

$$B = \frac{Y}{F} \qquad (39)$$

which can be used to estimate standing stock sizes given reliable estimates of Y and F, the latter being obtained, for example from the average of several single values of F from different species, as obtained from the mean length in the catch and an independent estimate of M.

Papers which may be consulted for obtaining more or less direct estimates of standing stock sizes in reefs are Bardach (1959) or Goeden (1978). The best reviews available to date of methods for use in coral reef fish studies are those of Russel *et al.* (1978) and the series of papers by Munro and co-authors (1973-1978) on the biology of Jamaican reef fishes and on the fishery based on these fishes.

Estimating the Biomass of Demersal Stocks

In areas where the sea bottom is smooth enough for trawling, standing stock sizes can be obtained from the relationship

$$B = \frac{\overline{c/f} \cdot A}{a \cdot x_1} \qquad (40)$$

where $\overline{c/f}$ is the mean catch per effort obtained during the survey (or for a given stratum), A the total survey area (or the area of the stratum in question) and "a" the area "swept" by the net during one unit of effort (e.g., one hour), x_1 being the proportion of the fish in the path of the gear that are actually retained by the net.

In Southeast Asian waters, a value of $x_1 = 0.5$ is commonly used (Isarankura, 1971; Saeger *et al.*, 1976; SCSP, 1978) and there is some evidence that this value might in fact be very realistic (Pauly, 1979a).

For the Western Indian Ocean south of the equator, it has been suggested, on the other hand, that all fish in the path of the trawl might be caught, which corresponds to $x_1 = 1$ (see Gulland, 1979, page 3).

The surface swept by the gear during one unit of effort is computed from the expression

$$a = t \cdot v \cdot h \cdot x_2 \qquad (41)$$

Where v is the velocity of the trawler over ground when trawling, h is the length of the trawl's head rope, t is the time spent trawling, and x_2 is a fraction expressing the width of the area swept by the net divided by the length of the head rope. In Southeast Asian waters, values for x_2 ranging between 0.4 (SCSP, 1978) and 0.66 (Shindo, 1973) have been used, with 0.5 possibly being the best compromise (see Pauly, 1979a).

Equations 40 and 41, incidentally can be used to obtain standing stock estimates from commercial trawlers, provided their catch per effort, head rope length and trawling speed are known.

The "swept area" method, as the method presented above is called, has been adapted - using certain assumptions as to the behaviour of fish - to line fishing over reefs (Wheeler and Ommaney, 1953), and this paper, along with the comments of Gulland (1979, page 4) should be consulted for details.

Estimating Maximum Sustainable Yield (MSY)

There are two basic models for estimating MSYs from fish stocks, namely the "yield-per-recruit" model of Beverton and Holt (1957) and its variants and the "surplus yield" model of Schaefer (1954) and its variants.

When suitable growth and mortality parameters are available, the model of Beverton and Holt (1957) or one of its simplified versions (e.g., Beverton and Holt, 1966) may be used to estimate yield-per-recruit, and if recruitment is known or assumed to be constant, to identify an optimal fishing strategy (but see Chapter 7 on overfishing). This model, however, will not be reviewed here, both because its complexity would lead us astray and because it tells us surprisingly little about how to manage a tropical multispecies fishery.

The Schaefer model - in its simplest version at least - is quite easy to handle. Here is a stepwise approach to estimating MSY by means of this model:

Step 1 Tabulate the catch and effort data and compute catch-per-effort figures (see Table 11).

Step 2 Plot the catch-per-effort values against their corresponding value of effort, and estimate the intercept (a) and the slope (b) by the linear regression technique. Change the sign of b from minus to plus.

Step 3 Compute MSY = $a^2/4b$
optimum effort = $a/2b$
yield for a given effort = $af - bf^2$

Steps 1-3 are illustrated in Figure 15, which is based on the data of Table 11.

Table 11

Catch, effort and catch/effort data to illustrate (the fitting of) the Schaefer Model[1/]

Year	Catch[2/]	c/f[3/]	f[4/]
1969	50	0.080	623
1970	49	0.078	628
1971	47.5	0.091	520
1972	45	0.088	513
1973	51	0.077	661
1974	56	0.061	919
1975	66	0.057	1 158
1976	58	0.032	1 970
1977	52	0.039	1 317

1/ From Dwippongo (1979)
2/ In tons · 10^3
3/ In tons . 10^3 per standard vessel
4/ Number of standard vessels

There is, finally, a third method for estimating maximum sustainable yields for a given fishery, and this is the comparative method.

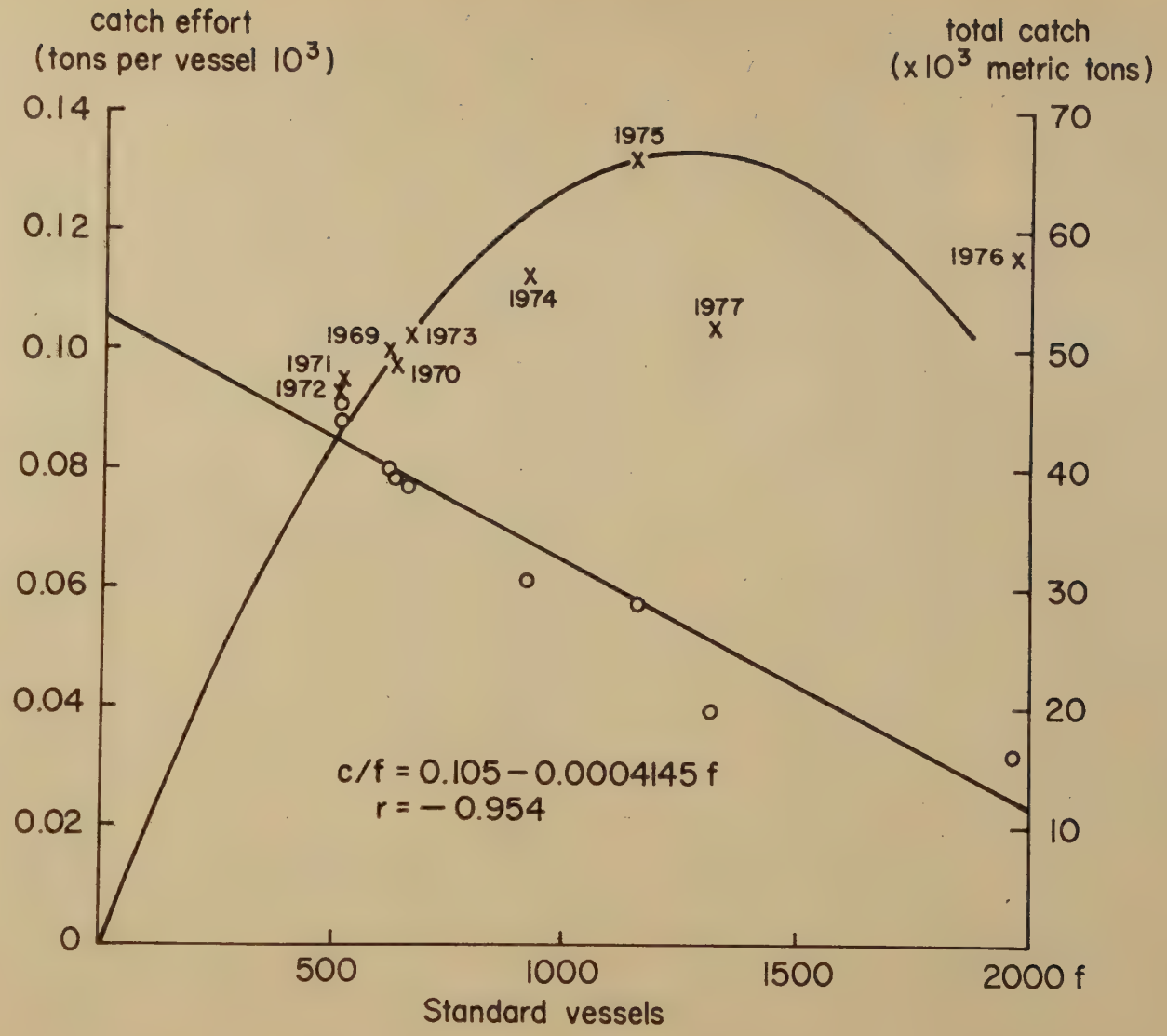

Figure 15 Trends of catch and catch-per-effort on effort, off the north Java coast. Based on data of Table 11. For fitting of "Schaefer Model" (see text)

Certain ecosystems are extremely productive (e.g., upwelling areas) or quite unproductive (such as the deep oceans). As far as tropical, shallow water systems are concerned, however, a remarkable consistency of yields (when expressed on a per area basis) can be noticed, with yield ranging between 4 and 8 t/km^2 (all fish) in inshore areas (including reefs) with values in excess of 10 t/km^2, where estuarine conditions boost productivity (Table 12). These figures may thus be used to assess certain stocks and fisheries, e.g., to assess if a certain stock is "underfished", or "optimally exploited".

Exercises: (1) Use the data of Table 13 to estimate MSY (per km^2) in the reefs of the Western Indian Ocean south of the equator.

(2) Discuss the state of the stock and of the fisheries (in the midseventies) at Mahé (Seychelles), and in Mauritius and propose regulatory measures.

Table 12

Selected values of fish MSY per surface area for different tropical ecosystems

Type of ecosystem	Location	MSY (t/km^2)	Source
Coral reef	Jamaica, Caribbean	4 (all fish)	Munro (1975)
	Western Indian Ocean	5 (all fish)	Gulland (1979)
Shelf	Gulf of Thailand (down to 50 m)	3.6 (demersal only)	SCSP (1978)
Estuaries and lagoons	San Miguel Bay (down to 15 m) (The Philippines)	15 (all fish)	Pauly and Mines (MS)
Shallow lagoons (estuarine conditions)	Gulf of Mexico (Texas)	12 (all fish)	Saila (1975)[1/]
	Sakumo Lagoon (Ghana)	15 (all fish)	Pauly (1976)

1/ Saila (1975) presents a compilation of data similar to those presented here, covering a wide variety of ecosystems ranging from the North Sea to tropical ponds

Table 13

Catch and catch/effort on the reef areas of the Western Indian Ocean south of the equator[1/]

Area	Current catch (t/km^2)	Catch/effort (kg/trap set)	Fishing Intensity (trap sets/km^2/year)
Mauritius	3.5	1.25	2 800
Tanzania (north)	4.7	3.45	1 400
Mahé (east coast)	1.37	5.37	260
Mahé (west coast)	3.12	5.07	620

1/ From Gulland (1979, page 9)

6. TWO FORMULAE FOR THE RAPID ESTIMATION OF POTENTIAL YIELDS IN (MORE OR LESS) VIRGIN STOCKS

Often, when the available data on the stocks of a certain area are insufficient for detailed assessment, approximate formulae must be used to estimate potential yields (=Py $\simeq$ MSY).

The simplest and most commonly used of this type of formulae has been proposed by Gulland (1971) and has the form

$$Py = M \cdot 0.5 \cdot B_v \qquad (42)$$

where B_v is the virgin standing stock, e.g., as estimated in a trawling or acoustic survey and M the (exponential) coefficient of natural mortality in the fish stock in question.

This equation was derived by Gulland (1971) from two different models:

A. From Beverton and Holt's yield-per-recruit model (1966) based on the assumptions that:

1. Recruitment remains more or less constant even under high levels of fishing mortality.

2. That no growth overfishing occurs, even at high levels of fishing mortality.

B. From the simple Schaefer model (1954), based on the assumptions that:

1. Virgin biomass (= B_v) is equal to "carrying capacity" (= B_∞) of the environment for the stock in question. (This is a tacit assumption, not explicitly stated by Gulland, 1971.)

2. That maximum sustainable yield (MSY) is extracted when the virgin stock is halved (at $B_v/2$).

3. That, when harvesting at the MSY level, fishing mortality (F) is roughly equal to the natural mortality (M):

In Southeast Asian demersal trawl fisheries, Equation 42 is generally used in conjuction with values of M set equal to unity (1), because Southeast Asian fishes are relatively small and short-lived. This value which is essentially a guess has been uncritically applied to a wide variety of stocks, including the multispecies stocks off the Northwest Australian Shelf. The paper by Sainsbury (1979) should be consulted for a reassessment of this value and some negative consequences of its use.

For the Western Indian Ocean south of the equator, a more conservative estimate of M = 0.5 has been suggested and used for assessing various stocks (Gulland, 1979).

A modification of Equation 42 has also been proposed (Gulland, 1979) which may be applied to lightly exploited stocks, namely

$$Py = Z_t \cdot 0.5\ B_t \qquad (43)$$

where Z_t is the exponential rate of total mortality (= F + M) in the year t, B_t being the standing stock size in that year. Needless to say, this equation is even more approximate than Equation 42 and its use is justified only as a very first approximation, when absolutely no other information on the fishery is available, and the fishery has been operating at a fairly constant level for several years.

A rather different approach may be proposed here:

In his derivation of the simple (parabolic) Schaefer model, Ricker (1975, page 315) arrives at equations, which, slightly rearranged give

$$MSY = \frac{r_m \cdot B_\infty}{4} \qquad (44)$$

where B_∞ is the carrying capacity of the environment for a given stock (and which may be assumed to correspond to B_v, the virgin stock size) while r_m ("k" of Ricker, 1975) is the "intrinsic rate of increase" of the population.

Thus, to obtain as estimate of MSY (or Py) all that is needed actually is an estimate of B_∞ (or B_v) and an independent estimate of r_m.

Blueweiss *et al.* (1978), using data published by various authors demonstrated that, for a wide variety of animals (including fishes),

$$r_m = 0.025 \cdot W^{-0.26} \qquad (45)$$

where r_m is expressed on a daily basis, and where W is the mean weight (in g) of the adult animals under consideration. Combining Equations 44 and 45 and converting to the year as a time unit, we obtain

$$Py = 2.3 \cdot W^{-0.26} \cdot B_v \qquad (46)$$

which can be used to estimate potential yields when virgin stock size and the mean weight (in g) of the adults in that stock are known. This equation, it will be noted, requires no estimate of M and may, therefore, be used for double-checking potential yield estimates based on Equation 42.

7. BIOLOGICAL OVERFISHING OF TROPICAL STOCKS[1/]

In recent years there has been a large number of publications describing the growth and subsequent decline of tropical fisheries, with much being written about the relatively well documented stocks in Southeast Asian waters. Almost none of these publications failed to mention that several, mainly demersal, stocks of the region are "overfished". "Overfishing" is indeed the primordial sin, the bankruptcy of fishery management. It is, in fact, the worst epithet a fishery biologist can hurl at the fishing community.

In spite of all this, relatively few attempts have been made to "translate" and apply to tropical stocks those concepts of overfishing that have been developed from considerations pertaining to temperate stocks. Some of these concepts are introduced here, together with some of their application to stocks in the region.

"Overfishing" may occur as (a) Growth overfishing; (b) Recruitment overfishing, or (c) Ecosystem overfishing.

Growth overfishing, which has hitherto received the greatest attention in the region occurs when the young fish that become available to the fishery (the "recruits") are caught before they can grow to a reasonable size. Thus, to the fishery biologist, the problem is to estimate the most suitable age (and/or size) at first capture and to suggest to the fishing community, e.g., the mesh size which by allowing younger (smaller) fish to escape, optimizes the yield that can be obtained from a given number of recruits.

The theory behind the computations used in estimating the optimal size at first capture and mesh size developed some 30 years ago by Beverton and Holt, also applies to tropical fish (Figure 16).

Thus, theoretically it should be possible to prevent growth overfishing in Southeast Asian waters except that at present no method can be conceived which would allow fishermen exploiting multiple-species stocks to catch the fish of each single species at their specific optimal size. This should ensure that we will have for the years to come quite a bit of growth overfishing in the region, especially as demersal fisheries go.

1/ Reprinted from an article published in the ICLARM Newsletter (Vol.2 (3):3-4) and dealing predominantly with Southeast Asian problems

Recruitment overfishing is quite another matter. This is what occurs when the (parent) stock is reduced, by fishing to the extent that not enough young fish are produced to ensure that the stock will maintain itself. Everybody knows that in any fish stock, there will be no young fish (= no recruits) if no parent fish are left by the fishery. These parents must mature, spawn, and fertilize eggs which hatch to larvae, only a very small fraction of which eventually survive and become fully formed young fish (recruits).

Generally the females of most fish species produce several thousands of eggs, sometimes even several millions as in the case of some commercially exploited species in temperate waters. To a certain extent this high fecundity has misled fishery biologists to assume that a very limited number of adult females would, in most fish stocks, be sufficient to replenish the number of recruits that eventually become available to the fishery.

Uncritically applied this assumption has been one of the causes of some of the most spectacular collapses in the world of fishing. Luckily this belief, that the lack of relationship between parent stock size and number of recruits should be the normal case in fishes is gradually replaced by its very opposite, namely, that most fish do display stock-recruitment relationships, the lack of such relationship being limited to a few groups such as the flatfishes and some gadoids. Strangely enough, apparently no attempt has been made to date to assess whether there is, in tropical stocks, an identifiable relationship between the size of a spawning stock and the number of recruits produced by this spawning stock, although it is true that data which could be used for such a purpose are scarce.

Using rather conventional methods[1/] and data from the Gulf of Thailand demersal trawl fishery, I have established stock-recruitment relationships in a number of species, one of which, pertaining to *Lactarius lactarius*, is shown here (Figure 17). The curve, which is a very typical "Ricker-curve", depicts the general pattern insofar obtained for most of the stocks I have investigated.

Only a few taxa showed no stock-recruitment relationships. Among these are the flatfishes (again!), one large predator (*Muraenesox*) and - by analogy (exact yield-per-recruit analysis was not performed) - the crabs, the shrimps and especially *Loligo*, whose spectacular increase in the Gulf of Thailand has been discussed by various authors.

Also, it appeared that in these taxa, there was a clear relationship between the number of their recruits (in any given year) and the standing stock size (for the same year) of their potential competitor and predators (as expressed by the biomass of all other taxa).

This last point - competition and predation between taxa - leads us to the third form of overfishing, namely, ecosystem overfishing. Ecosystem overfishing is a "soft concept", allowing for much loose talk because it is not clearly defined. It may be described here as what takes place in a mixed fisheries when the decline (through fishing) of the originally abundant stocks is not fully compensated for by the contemporary or subsequent increase of the biomass of other exploitable animals.

Thus, as suggested by modern ecological theory, ecosystem overfishing would be the transformation of a relatively mature, efficient system into an immature (or stressed), inefficient system. This, to a large extent, is what happened in the Gulf of Thailand where a (presumably) stable and efficient high biomass system dominated by teleostean fish was gradually turned into a (presumably) unstable and inefficient low biomass stock in which the role of invertebrates has markedly increased (note the reversal of the evolutionary sequence!).

All three forms of overfishing discussed here occur in Southeast Asian waters, and the theory of fishing could well benefit from a study of the experience gained in the region.

1/ Swept-area method for estimating standing stock and fishing mortality, computation of yield-per-recruit and division of Y/R into catch to obtain recruit numbers, plus miscellaneous methods and assumptions for obtaining other parameters estimates and data standardization.

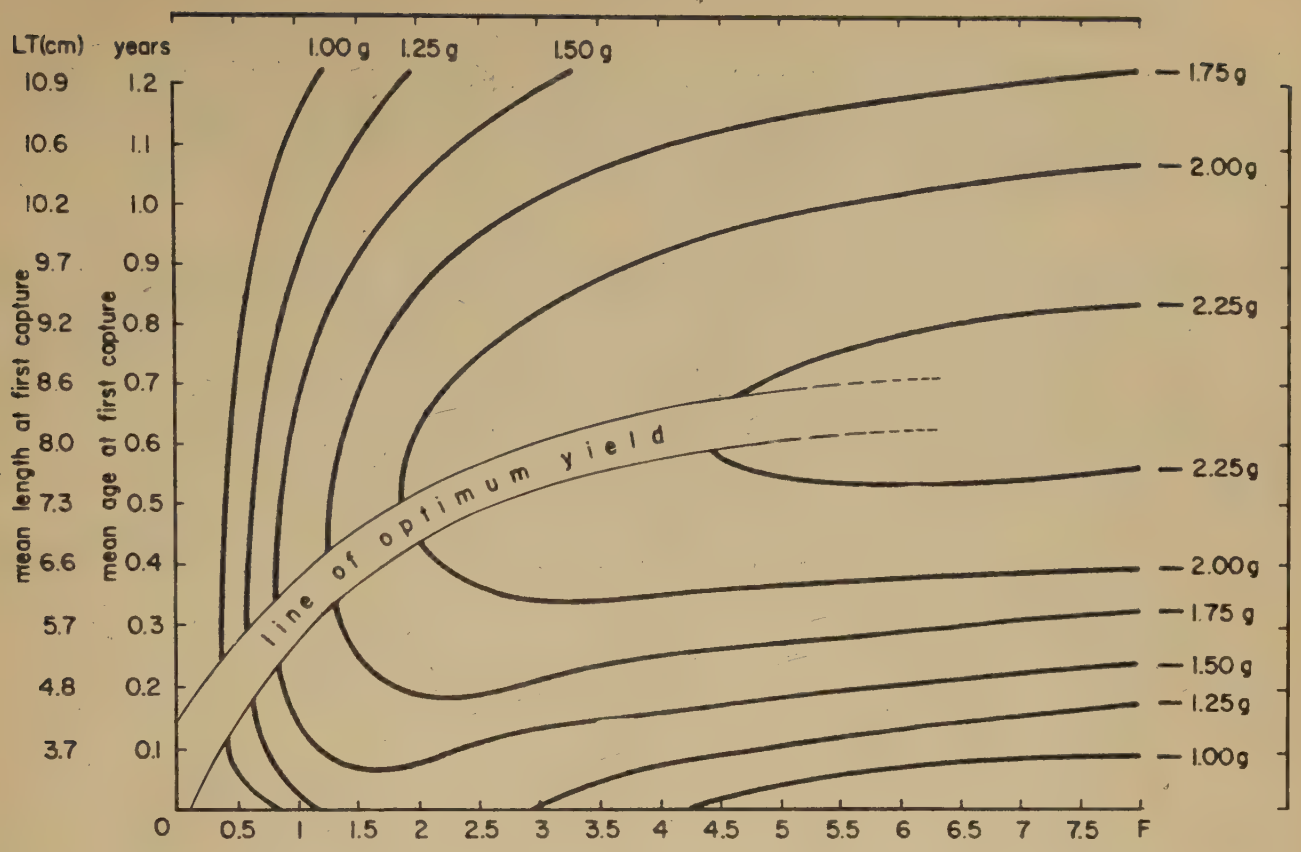

Figure 16 The yield/recruit in relation to size or age at first capture (ordinate) and the force of fishing (abscissa) of the slipmouth *Leiognathus splendens*. The Beverton and Holt method was used to calculate the diagram

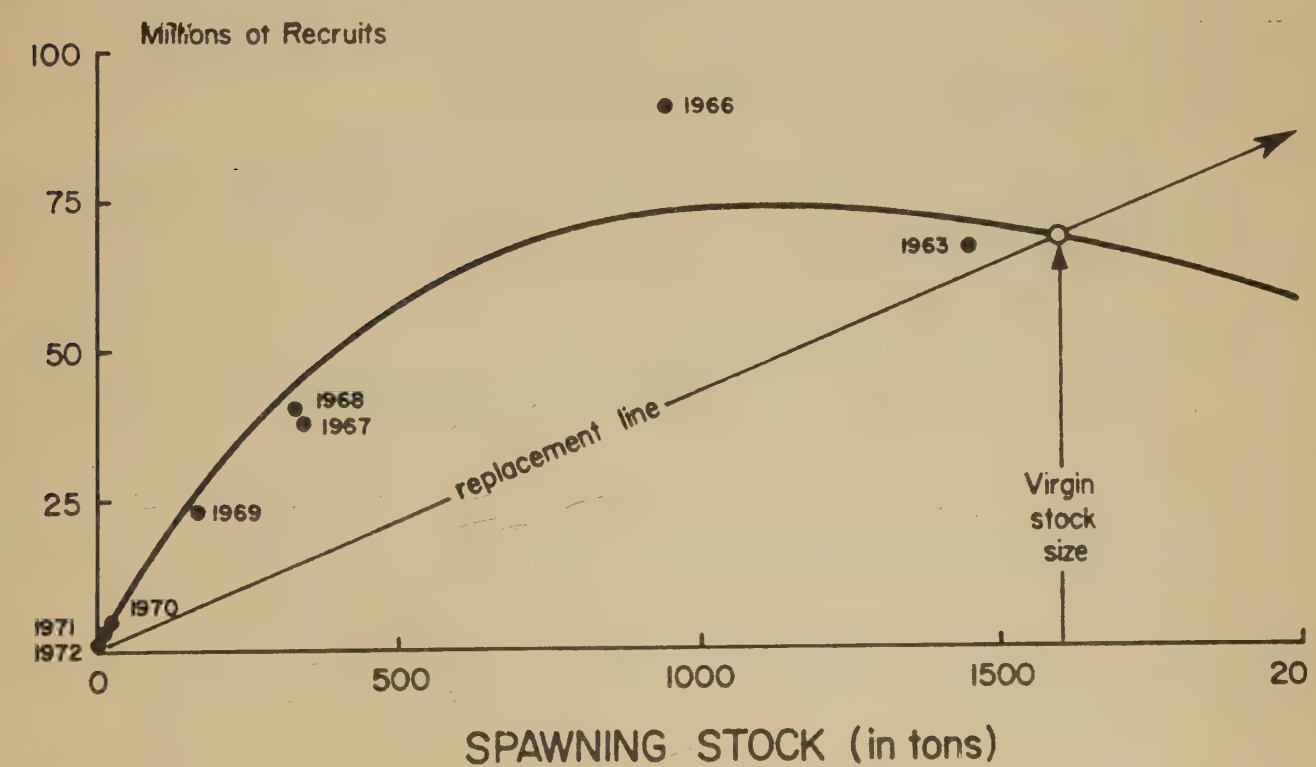

Figure 17 Stock-recruitment relationship for the stock of *Lactarius lactarius* in the Gulf of Thailand

Also, as biological processes in the tropics often occur in "pure form", unmediated by strong fluctuations of the abiotic environment (as occur in temperate waters, which are temperate only on the average), it is even thinkable that the theory of fishing, especially as far as multispecies stocks are concerned, could make here in Southeast Asia one step or two into scientifically unexplored territory.

Furthermore, understanding the nature of overfishing should considerably help solve resource allocation problems which have traditionally marred the relationships between artisanal and commercial fishermen in the region. It will, for example, become obvious that the catch, say of 100 t of relatively young fish by artisanal fishermen fishing close inshore has a radically different effect on a stock than the catch of 100 t of older and larger fish by a commercial fishery operating further offshore. This feature should indeed lead to the understanding that rather than having one single maximum yield, a given stock may have several "optimum sustainable yields" whose respective magnitudes depend mainly on the mode of operation of the fishing gear used as well as on the resulting age composition of the catch.

Finally, it is on the basis of the identification of such conflicting "OSYs" that fishery managers of the region can make sound decisions as to which segments of the fishing community should be encouraged or dissuaded from fishing.

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(The paper in which the original "Schaefer Model" is presented. The elaborate computation proposed in this original version are to a large extent superfluous, and simplified versions of this model are now used (see, e.g., Ricker, 1975))

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(As per title)

APPENDIX 1

Critical values for correlation coefficients

Critical r			Critical r		
df	P = 0.05	P = 0.01	df	P = 0.05	P = 0.01
1	0.997	1.000	19	0.433	0.549
2	0.950	0.990	20	0.423	0.537
3	0.878	0.959	25	0.381	0.487
4	0.811	0.917	30	0.349	0.449
5	0.754	0.874	40	0.304	0.393
6	0.707	0.834	50	0.273	0.354
7	0.666	0.798	60	0.250	0.325
8	0.632	0.765	70	0.232	0.302
9	0.602	0.735	80	0.217	0.283
10	0.576	0.708	90	0.205	0.267
11	0.553	0.684	100	0.195	0.254
12	0.532	0.661	125	0.174	0.228
13	0.514	0.641	150	0.159	0.208
14	0.497	0.623	200	0.138	0.181
15	0.482	0.606	300	0.113	0.148
16	0.468	0.590	400	0.098	0.128
17	0.456	0.575	500	0.088	0.115
18	0.444	0.561	1 000	0.062	0.081

df (= "degrees of freedom") is equal to the number of observations (data pairs) minus two (thus df = n-2)

P = 0.05 and P = 0.01 refer to the probability of 5 and 1 percent, respectively, that the correlation, although "significant" is still the result of chance

APPENDIX 2

Growth parameters of selected Indo-Pacific fish stocks

The following two pages list the growth parameters L_∞ and K of 71 stocks of Indo-Pacific fishes, distributed in 64 different species. The stocks are grouped by species and genera, then by families, the latter being ordered alphabetically for easier access.

The data are selected from an earlier, more comprehensive compilation of growth parameters (Pauly, 1978a) in which data for 1 500 stocks, distributed in more than 500 species were given. What is reproduced here, however, includes most of the tropical Indo-Pacific stocks given in the earlier compilation.

I have made no attempt to document here the sources of the growth parameters, or of the data from which parameter values were calculated (but see Pauly, 1978a).

As a rule, the growth parameters given here should be used only for comparative purposes and to get a "feel" for the growth of some tropical Indo-Pacific fishes. Should, however, any of these data be used for stock assessment purposes, then an attempt should be made to make sure that the pair of growth parameters used is compatible with the stock in question. This involves the following criteria and techniques:

(1) The value of L_∞ used should be slightly larger than the largest fish observed from the stcok from which the assessment is to be made.

(2) When parameter values for a given species are not available, parameter values pertaining to another closely related species (e.g., same genus) may be used, granted the rule in (1) applies.

(3) In fishes, L_∞ is inversely correlated with K, and this may be described by the relationship

$$\log_{10} K = a - 2/3 \log_{10} L_\infty^3$$

This relationship may be used in conjunction with a given set of L_∞ and K values to estimate the value of a for a given species then obtain values of K for another set of values of $L_{(\infty)}$.

(4) In general, a low value of L_∞ and a high value of K are correlated with a high environmental temperature, while high L_∞ and low K indicate relatively lower temperature. This rule should be considered when making the adjustments in (3) and (2).

Family	Species	L_∞ 1/	K 2/	Location
Acanthuridae	*Acanthurus triostegus*	21.7	0.35	Oahu, Hawaii,
Apogonidae	*Apogon cyanosoma*	9.4	2.9	Eilat, Red Sea
Callionymidae	*Callionymus belcheri*	10.8	0.44	Moreton Bay, Australia
Carangidae	*Decapterus macrosoma*	24.4	0.95	Palawan, the Philippines
Carangidae	*Selaroides leptolepis*	20.0	1.16	Gulf of Thailand
Centropomidae	*Lates calcarifer*	113.0	0.19	Papua New Guinea
Chirocentridae	*Chirocentrus nudus*	87.2	0.242	India, 9°N 72°20'E
Clupeidae	*Sardinella albella*	13.0	1.65	Gulf of Manaar, India
Clupeidae	*Sardinella fimbriata*	18.4	1.32	Karwar, India
Clupeidae	*Sardinella sirm*	22.6	0.65	Al-Gardaqa, Red Sea
Clupeidae	*Hilsa ilisha*	51.1	0.49	Mandapam area, India
Clupeidae	*Anadontostoma chacunda*	20.8	0.87	Godavary Estuary, India
Engraulidae	*Stolephorus indicus*	21.8	0.712	Singapore Strait
Engraulidae	*Stolephorus pseudoheterolobus*	10.3	2.08	Singapore Strait
Engraulidae	*Thrissodes mystax*	23.6	0.76	Malabar Coast, India
Gerridae	*Gerres punctatus*	27.0	1.8	Ambaro Bay, Madagascar
Harpadontidae	*Harpadon neherus*	35.0	0.52	Bombay area, India
Holocentridae	*Holocentrus diadema*	16.8	1.13	Eilat, Red Sea
Istiophoridae	*Tetrapterus audax*	312.0	0.201	East Africa, 5°S 43°E
Lactariidae	*Lactarius lactarius*	32.0	0.854	Waltair, India
Leiognathidae	*Leiognathus equulus*	21.2	1.75	Ambaro Bay, Madagascar
Leiognathidae	*Leiognathus splendens*	14.3	1.04	San Miguel Bay, the Philippines
Lethrinidae	*Lethrinus enigmaticus* ♂	62.6	0.15	Indian Ocean, 10°30'N, 62°E
Lethrinidae	*Lethrinus enigmaticus* ♀	52.6	0.18	Indian Ocean, 10°30'N, 62°E
Lethrinidae	*Lethrinus lentjan*	64.0	0.27	Gulf of Manaar, India
Nemipteridae	*Nemipterus bleekeri*	30.4	0.44	Off Brunei
Nemipteridae	*Nemipterus hexodon*	27.8	0.49	Off Brunei
Nemipteridae	*Nemipterus delagoae*	27.8	0.70	Off Brunei
Nemipteridae	*Nemipterus marginatus*	28.4	0.37	Off Brunei
Nemipteridae	*Nemipterus mesoprion*	19.5	0.63	Off Brunei
Nemipteridae	*Nemipterus nematophorus*	27.3	0.53	Off Brunei
Nemipteridae	*Nemipterus nemurus*	28.9	0.26	Off Brunei
Nemipteridae	*Nemipterus peronii*	28.9	0.46	Off Brunei
Nemipteridae	*Nemipterus tolu*	26.8	0.52	Off Brunei
Plotosidae	*Plotosus anguillaris*	27.0	0.45	Ago Bay, Japan
Polynemidae	*Polynemus indicus*	150.0	0.189	East coast of India (22°N)
Pomacentridae	*Amphiprion chrysopterus*	11.3	0.81	Eniwetok, Atoll
Pomacentridae	*Amphiprion tricinctus*	16.5	0.36	Eniwetok, Atoll
Pomadasydae	*Pomadasys hasta*	62.4	0.50	Bombay, India
Pomadasydae	*Rhonciscus striatus*	18.0	0.30	Gulf of Suez
Pomatomidae	*Pomatomus saltatrix*	84.0	0.20	Natal, South Africa
Psettodidae	*Psettodes erumei* ♂	50.9	0.265	Gulf of Thailand
Psettodidae	*Psettodes erumei* ♀	31.1	0.33	Gulf of Thailand
Sciaenidae	*Sciaena russelli*	18.5	1.01	Gulf of Thailand
Sciaenidae	*Otolithoides brunneus*	160.0	0.21	Bombay, India
Sciaenidae	*Pseudosciaena coibor*	75.0	0.39	Chilka Lake, India
Sciaenidae	*Pseudosciaena diacanthus*	122.0	0.30	Bombay, India
Scombridae	*Rastrelliger kanagurta*	21.8	5.16	Cochin, India
Scombridae	*Rastrelliger kanagurta*	22.4	4.32	Karwar, India
Scombridae	*Rastrelliger kanagurta*	42.0	0.3	Al-Gardaqa, Red Sea
Scombridae	*Rastrelliger neglectus*	20.9	4.2	Gulf of Thailand
Scombridae	*Rastrelliger neglectus*	22.9	2.28	Western Borneo
Scombridae	*Pneumotophorus japonicus*	27.9	0.485	Red Sea, Egyptian Waters

Family	Species	L_∞ 1/	K 2/	Location
Serranidae	*Anthias squampinnis*	16.8	0.60	Eilat, Red Sea
Siganidae	*Siganus canaliculatus*	25.2	1.87	Southern Negros, the Philippines
Sillaginidae	*Sillago sihama*	28.1	0.75	Gulf of Manaar, India
Sparidae	*Acanthophagus bifasciatus*	48.1	0.18	Gulf of Aden
Sparidae	*Argyrops spinifer*	96.4	0.08	Gulf of Aden
Sparidae	*Argyrops filamentosus*	45.6	0.28	Gulf of Aden
Sparidae	*Polysteganus undulosus*	98.4	0.18	Delagoa Bay, South Africa
Sparidae	*Pagellus natalensis*	45.5	0.20	Gulf of Aden
Synodontidae	*Saurida tumbil*	43.6	0.43	Manila Bay, The Philippines
Synodontidae	*Saurida undosquamis*	37.9	0.89	Gulf of Thailand
Thunnidae	*Auxis thazard*	61.0	0.83	Sri Lanka
Thunnidae	*Euthynnus affinis*	90.0	0.44	Seychelles
Thunnidae	*Thunnus tonggol*	110.0	0.32	Northern Australia
Thunnidae	*Katsuwonus pelamis*	85.1	0.95	Hawaii
Thunnidae	*Katsuwonus pelamis*	84.6	1.16	Hawaii
Thunnidae	*Katsuwonus pelamis*	62.3	0.98	North of Madagascar
Thunnidae	*Thunnus obesus*	196.0	0.167	Hawaii
Trichiuridae	*Trichiurus lepturus*	98.0	0.20	Madras, Mangalore, India

1/ Total length, in cm, except for the Thunnidae in which fork length in cm is used
2/ Annual basis

APPENDIX 3

Length frequency sheet

Vessel Name

Species Name

vessel code	cruise number	station number	sample number	day	month	year	minimum length	maximum length	length increment	Species code			Stratum code			total catch .kg.			sample wt. kg.		raising Factor		sheet number

Length Scale cm.

	0.0	0.5	1 0	1.5	2.0	2 5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	0.0	.0.5	1.0	1.5	2.0
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4
S																									
C																									

	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
S																									
C																									

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